A MANUAL OF
DETERMINATIVE MINERALOGY

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BY

CHARLES H. WARREN, Ph.D.
Professor of Mineralogy at the Massachusetts Institute of Technology, Cambridge, Mass.

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AUTHOR'S NOTE

THIS manual was originally written and privately printed for use in the beginner's course in mineralogy at the Massachusetts Institute of Technology. There are several excellent textbooks covering elementary crystallography and descriptive mineralogy which are quite satisfactory in these particulars. On the determinative side, in the writer's opinion, they leave much to be desired. The comprehensive work by Brush and Penfield is, of course, an indispensable adjunct to any mineralogical laboratory, but to require students to purchase it in addition to a descriptive textbook appeared to be asking a good deal of them. It was, therefore, for the purpose of enabling the student to supplement his descriptive text and crystallography with a relatively inexpensive but satisfactory determinative text that this manual was compiled. Experience with its use, over a period of several years, has demonstrated that it gives satisfactory results both as an aid in the determination of the more common minerals and as a means of training the students in the systematic examination of mineral material generally. Thinking that perhaps other teachers of mineralogy might also find it useful as an auxiliary text, the author has arranged for its publication.

AUTHOR'S NOTE TO SECOND EDITION

Since this manual was published, the author's attention has been called to the omission of certain tests which might well have been included in the text. They are as follows:

Flame Test for Manganese.—Manganese minerals if moistened with hydrochloric acid and ignited B.B., or on a platinum wire in the Bunsen flame, yield a yellowish-green flame color.

Test for Cerium.—If a little red lead is added to a nitric acid solution, the solution boiled, and allowed to settle, it will be colored orange if cerium is present.

Test for Cassiterite, SnO_2.—Grains of cassiterite, if put in dilute hydrochloric acid with a piece of metallic zinc, become, in a short time, covered with a gray, metallic coating of tin.

Cæsium, Cs.—Hydrochlorplatinic acid added to a hydrochloric acid solution containing cæsium, produces a fine yellow precipitate of Cs_2PtCl_6.

LIST OF ABBREVIATIONS USED IN THE TEXT AND TABLES

B.B.	Before the Blowpipe
B. & P.	Brush and Penfield's Determinative Mineralogy
Clv.	Cleavage
Char.	Charcoal
Cmm.	Cubic millimeter
CC.	Cubic centimeter
Conc.	Concentrated
Cryst.	Crystal or Crystalline
C. T.	Closed Tube
Diff.	Difficultly
F.	Fusibility
Gran.	Granular
H.	Hardness
Hex.	Hexagonal
I.	Isometric
Isom. w.	Isomorphous with
Mass.	Massive
M.	Monoclinic
O.	Orthorhombic
O.F.	Oxidizing Flame
O.T.	Open Tube
Perf.	Perfect
Pinc.	Pinacoidal
Ppt.	Precipitate
Prism.	Prismatic
R.F.	Reducing Flame
Rhomb. or R.	Rhombohedral
Sol.	Soluble
Sp.G.	Specific Gravity
T.	Tetragonal
Tric.	Triclinic
U.	Usually
Volt.	Volatile

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DETERMINATIVE MINERALOGY

CHAPTER I

THE USE OF THE BLOWPIPE, ETC.*

Making the Blowpipe Flame.—What is known as the " blue cone " blowpipe flame is made by inserting the tip of the blowpipe into a small luminous gas, or a large candle flame, and blowing through it a steady current of air from the cheeks. A blowpipe fitted with a small " trumpet " mouth-piece, will, in general, be found the least tiresome to the lips. The pipe may conveniently be held between the thumb and first three fingers of the right hand, the forearm being allowed to rest on the edge of the desk. This manner of holding gives the greatest freedom for manipulating the pipe, and makes it easy to control the direction of the flame.

In blowing, the cheeks are used exactly like a pair of bellows, being kept distended by a continuous supply of oxygen-rich air from the throat, regular breathing meanwhile going on as usual. With a little practice it will be found that a continuous stream of air under moderate pressure can be blown through the pipe

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* For a list and description of apparatus and reagents desirable for work in determinative mineralogy reference may be made to Brush & Penfield's " Determinative Mineralogy and Blowpipe Analysis."

Sets of Blowpipe apparatus for mineralogy and also for blowpipe assay work are sold by The Marine Compass Co., Bryantville, Mass.; by the Chemists' & Surgeons' Supply Co., Lim., 32 McGill College Ave., Montreal, Canada. Very complete outfits are also listed by Eimer & Amend, 211 Third Ave., New York.

for some time. The student should practice at making this flame until he can maintain a steady flame having a sharply defined blue cone about three centimeters long for several minutes. In case the blowpipe gives an irregular and poorly shaped flame, or one of improper length, the hole in the pipe should be bored out carefully with a small, tapered, steel reamer.

In the laboratory, the ordinary Bunsen burner may be adapted for use with the blowpipe by slitting and opening the top of the tube on one side for about two centimeters. The holes for the admission of air at the base should be kept tightly closed. In places like the field, where gas is not available, the flame furnished by a thick, flat, and nicely trimmed wick, which dips into tallow or other hydro-carbon fuel, capable of yielding a luminous flame, rich in unburned hydrocarbon gases and carbon, may be used.

The "Blue Cone" Blowpipe Flame.—The blowpipe flame made as described above, like the familiar "Bunsen" flame, consists of three parts or cones, or four if we count an outer and

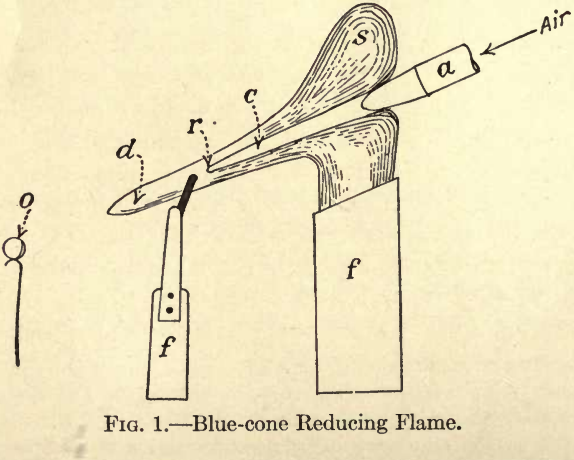

Fig. 1.—Blue-cone Reducing Flame.

practically invisible cone. Within the sharply defined "blue cone" (at *c*, see Fig. 1) is unburned hydrogen and carbon, the products of the dissociation of the hydrocarbon fuel, and air from the pipe. Then follows a very thin envelope (*r*) deep blue in color in which the combustion is very active and is concerned chiefly with the burning of the carbon to carbon monoxide. This, with the hydrogen, is carried on into the next cone (*d*), where the carbon monoxide is oxidized to carbon dioxide and the hydrogen to water vapor. Outside of this cone, which is not very sharply defined, we have a zone of hot gas or vapor which is completely oxidized. Many substances containing oxygen, if held in cone *d*, will yield up part, or all, of their oxygen under the action of the highly heated carbon monoxide and be *reduced*, the carbon monoxide becoming carbon dioxide. This part of the flame is therefore called the "*Reducing Flame*" usually designated by the abbreviation R.F.

Experiment No. 1.—Test a small splinter of Hematite, Fe_2O_3, with a magnet. Next heat the splinter in the forceps B.B. in the *reducing flame* (in cone *d*, immediately beyond the point of the *blue cone*), and after the splinter has been allowed to cool, test it again with the magnet. The reaction is $3Fe_2O_3+CO=2Fe_3O_4+CO_2$.

If a substance capable of oxidation is heated at a point about three centimeters beyond the point of the blue cone, viz., in the outermost zone of the flame (at *o*), where there cannot be reducing action and where oxygen from the air can and does mix with the hot gases of the flame, it will take on oxygen and become oxidized. This part of the flame is therefore called the "*Oxidizing Flame*," usually designated by the abbreviation O.F. The oxidizing part of the flame is much cooler than the reducing flame, so that, as a rule, it requires a considerably longer exposure in this flame to produce oxidation than it does to accomplish reduction in the reducing flame.

Experiment No. 2.—Take a splinter of Hematite and treat it as in Exp. No. 1, except that it should be heated only an instant in the R.F., or just long enough to render it magnetic. Next reheat this splinter for several minutes in the O.F. After cooling, test it again with the magnet. It should have lost its magnetic properties if the oxidation has been complete. What is the chemical change here?

The hottest part of the flame is at the point of the *blue cone r*, indeed, the temperature is sufficiently high at this point to melt a small platinum wire. It should be remembered, however, that, although the flame is locally very hot, it is also small, and the size of the fragment or assay which is to be heated in the flame should be gauged accordingly.

The Smoky Reducing Flame.—If the tip of the blowpipe is held just outside of the flame, and a gentle current of air is blown across and downward through the flame, what is known as the *smoky reducing flame* is produced. This flame is somewhat luminous, much less sharply outlined than the other flame, and is essentially a reducing flame, since it contains still an excess of unburned and partially burned carbon. Although its temperature is considerably lower than that of the blue-cone flame, it is, nevertheless, on account of its strong reducing qualitites, especially useful in operations, such as the production of the lead button in the blowpipe-silver assay, where a strong reducing action is necessary, but where a very high temperature is either not needed or is undesirable.

THE TESTING OF MATERIALS BEFORE THE BLOWPIPE

Heating in the Platinum or Chromel Forceps.*—By simply heating small fragments held in the forceps in the blowpipe flame, facts may be learned regarding substances, particularly minerals, which are useful in determining their identity. Indeed it may be said that after a study of the purely physical characteristics of a mineral, the next step towards its identification is to heat a fragment B.B., in the forceps. Careful observation of every detail of its behavior will very often furnish useful information.

In performing this operation a fragment should generally be

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* Forceps tipped with a nickel-chromium alloy "Chromel" are much cheaper, and quite as satisfactory as those tipped with platinum.

chosen about the diameter of an ordinary pencil lead and 3 or 4 mm. long. It is held in the forceps so that the greater portion of it is free of the forceps and somewhat inclined toward the flame. It should then be introduced into the cooler portion of the flame first, and then, if necessary, moved up to a position very near the point of the blue cone, viz., the hottest part of the flame. The position of the fragment with reference to the flame is shown in Fig. 1.

The more important phenomena that may be observed in this connection are: *a*, degree of fusibility; *b*, manner of fusing; *c*, decrepitation, crumbling; *d*, volatility; *e*, changes of color, glowing; *f*, formation of a strongly basic oxide; *g*, flame colorations; *h*, magnetic properties.

(*a*) *Degree of Fusibility.*—The determination as to whether a mineral can or cannot be melted (fused), and if it can be, the degree of ease with which this can be accomplished, is a matter of the first importance in the determination of minerals. For purposes of easy comparison the so-called " scale of fusibility " has generally been adopted. This scale is given below, and consists of a series of five common minerals, arranged in order of their apparent increasing resistance to fusion.

If a mineral fuses B.B. its ease of fusion is compared with those of the standard minerals of the scale, and its relative fusibility thus determined. Care should be taken in the case of easily fusible or volatile compounds, especially those of metallic appearance, not to allow them to melt on to the forceps, particularly if platinum is used. Care should also be taken to have only one end of the fragment in the flame, so that as little heat as possible may be conducted away by the forceps. If a fragment of the standard size suggested above is used, and little or no melting takes place, it is well to select smaller, very thin splinters and test them. With minerals that fuse with great difficulty, such as No. 5 of the scale, the melting is generally only a rounding of the point or thin edges, and careful examination with a hand lens should be made before and after heating. It is obvious that in comparing different minerals in regard to their relative fusibility that fragments of as nearly the same size and shape as possible should be chosen.

For the manner of handling minerals which decrepitate B.B., see p. 7.

Scale of Fusibility

No. 1. Stibnite, Sb_2S_3.

Fuses easily in the luminous lamp or gas flame. Fusible at a low red heat in the closed glass tube.

No. 2. Chalcopyrite,* $CuFeS_2$ or Natrolite, $Na_2Al_2Si_3O_{10}, 2H_2O$. Fuses in a luminous gas or lamp flame. Fuses in the closed tube at a full red heat.

No. 3. Almandite (Garnet), $Fe_3Al_2(SiO_4)_3$. Fuses readily before the blowpipe. Can be fused without much difficulty into a globule.

No. 4. Actinolite, $Ca(Mg,Fe)_3(SiO_3)_4$. The edges can be readily rounded before the blowpipe. Very thin splinters fuse to a globule.

No. 5. Orthoclase, $KAlSi_3O_8$. The edges can be rounded with some difficulty; extremely thin splinters can be fused to a globule by long continued heating.

Although *exceedingly* thin splinters of minerals which have a higher melting point than No. 5 of the scale can sometimes be distinctly rounded B.B., it is customary in Determinative Mineralogy to class all such as, "*Fusible above 5,*" or simply as "*infusible, B.B.*"

In order to determine the fusibility of substances which decrepitate when heated, they may be finely powdered, moistened to a paste with a little water, and then heated on a charcoal support;

Experiment No. 3.—Test the fusibility of the minerals given in the "scale of fusibility." Make the tests first with fragments of standard size, then with larger and smaller fragments. Try very thin splinters with

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* In using this mineral, slow heating should be avoided, for this may allow oxidation to take place, and if this occurs to any considerable extent, the fusibility is decreased.

Nos. 4 and 5. Note with No. 1, Stibnite, that it volatilizes rapidly with the formation of white fumes of antimony oxide and a pale greenish flame color. Care should be taken not to allow the melted portions of this mineral to touch the forceps.

(*b*) *Manner of Fusing; intumescence, swelling, exfoliation, branching, etc.*—Fusion accompanied by more or less boiling or bubbling (intumescence) during a part or all of the period of heating is a peculiarity of many minerals, particularly those containing chemically combined water or other constituents driven off during melting. The fused fragments of such minerals are apt to be scoriaceous or full of bubbles. A few minerals exfoliate (leaf out), or branch, or swell, either before or during fusion.

EXPERIMENT No. 4.—Heat fragments of stilbite and lepidolite, noting in the case of the first, the branching and intumescence, in the second, the intumescence and flame color, and in both, the appearance of the well fused mass.

(*c*) *Decrepitation and Crumbling.*—Many minerals decrepitate B.B. and some, like fluorite, always decrepitate when heated. Decrepitation is apt to occur with minerals containing liquid inclusions, and also in many minerals possessing excellent cleavages. In the latter case decrepitation is to be ascribed to violent rupture along planes of weakness under the action of the stresses set up by rapid expansion. In many cases, however, the decrepitation seems to be due to some structural peculiarity of the individual specimen, and appears to be independent of cleavage or inclusions. One specimen of chalcopyrite, for example, will decrepitate violently, while another will show no signs of it.

Minerals which decrepitate so badly that fragments cannot be used for testing their fusibility, etc., in the forceps, or that fly from the charcoal, may either be heated in a hard glass tube (C.T.) until decrepitation ceases, or they may be powdered finely in a mortar, and then some of the powder, thus obtained, may be put on the charcoal, and after moistening with water, may be scraped into a compact little heap and tested B.B. as desired.

A few minerals, chiefly infusible carbonates of the alkali-earth elements, or hydrated oxides, powder or crumble B.B. Such behavior generally points to the loss of some constituent such as CO_2 or H_2O.

(*d*) *Volatilization,* partial or complete, may occur. This is generally accompanied by fusion, though not always, and since it is commonly some oxide-forming element (as Sb,Pb,S, etc.), evidence of such behavior is generally obtained in the fumes arising from the fragment, or by a characteristic odor, or by a flame color. In such cases further tests on charcoal, or in the open and closed tubes, are usually in order.

(*e*) *Changes of Color. Glowing.*—When minerals of non-metallic appearance turn black on being heated B.B., it generally indicates the presence of either iron, manganese, or copper. The color assumed by a fragment after heating should always be noted.

With minerals of non-metallic appearance we may make the following divisions, based on the character of the fusion, which are useful in determinative work (see tables pp. 129–137).

Minerals that fuse to: (*a*) a clear glass.
(*b*) a white glass, or enamel.
(*c*) a colored (yellow-brown-greenish) glass, enamel, or slag.
(*d*) a black enamel or slag.

Intense **glowing,** or the emission of a **white light,** by the heated fragments may in general be taken as an indication of great infusibility.

(*f*) *Formation of a Strongly Basic Oxide.*—When fragments of the carbonates, sulphates, and halogen salts of the alkali and alkaline-earth metals are heated intensely B.B. they are, to a greater or less extent, decomposed, yielding the oxide. If the fragment is placed on a piece of moistened turmeric paper or reddened litmus paper, an *alkaline reaction* (shown by a brown (turmeric) or blue (litmus) coloration of the paper) will result, due to the formation of an alkaline hydrate. As the number of such salts occurring as minerals is small, this test is a very useful one in determining such minerals (see Table, p. 128).

(*g*) *Flame Colorations.*—Fragments of minerals containing one of the elements yielding a characteristic flame color often impart the color to that portion of the blowpipe flame that shoots out beyond the fragment. Except in the case of very volatile metallic compounds, and of sodium-bearing minerals in general, the coloration of the blowpipe flame amounts to little more than a mere *sliver* of color and may be easily overlooked. In some cases strong and prolonged ignition may be required to produce a satisfactory coloration. Flame colorations obtained from fragments should generally be verified by flame tests made as described beyond under another heading, p. 19. The yellow flame of sodium is often obtained at first with almost any fragment that has stood about the room, or been handled, but it usually burns off quickly.

Experiment No. 5.—Observe the flame colors obtained by heating fragments of strontium sulphate (celestite) or the carbonate (strontianite) and barium carbonate (witherite) or sulphate (barite) B.B. Place the fragments after heating on a piece of moistened turmeric paper and note the alkaline reaction resulting. Consider the reactions of this experiment.

(*h*) *Magnetic Properties.*—In the cases where the fragment turns black, with or without fusion, it is well to prolong the heating in R.F., and then to test the cold sample with a magnet, to see if it is attracted by the magnet because of the presence of any considerable quantity of iron, or, more rarely, nickel or cobalt.

Experiment No. 6.—Heat a small fragment of garnet, for a considerable time at the point of the blue cone. Note that it turns black, and when cold can be picked up with the magnet. Heat a fragment of siderite, $FeCO_3$, for a short time B.B. and test the cold fragment with a magnet.

HEATING BEFORE THE BLOWPIPE ON CHARCOAL

Rectangular blocks of compact charcoal are much used in blowpipe work for various operations. These may be summarized as follows:

(*a*) Testing the fusibility of (1) metallic minerals containing volatile elements likely to injure the forceps and (2) of powdered materials.

(*b*) Reduction of metals from their minerals with and without the aid of fluxes.

(*c*) Formation of sublimates—chiefly metallic oxides (with or without the aid of fluxes).

(*d*) Roasting of metallic minerals to remove volatile oxidizable constituents, such as sulphur, arsenic, etc.

(*e*) The decomposition with fluxes of refractory silicates, oxides, etc., chiefly in order to render them soluble in acids.

(*a*) For simple fusion tests, as well as for other operations, the charcoal stick is held generally in a flat position or one slightly inclined to the horizontal, and in a position so that the direction of the blowpipe flame is with the long way of the coal. The flame is directed so that it strikes the surface at an angle of about 45°, although this angle is often varied considerably, according to the requirements of any particular experiment or part of an experiment. Sometimes, where a fragment is to be heated, or where a very fluid melt or a globule is likely to result, a shallow depression is scraped in the surface of the coal with a knife or other convenient instrument. In general, however, the use of the flat surface is to be recommended, since with a little practice no difficulty will be found in keeping the substance in place on the flat coal, and in cases where coatings may be formed, a flat surface receives them much better, and also permits of their being examined to better advantage, than one having a hole in it. In all cases where a powdered material (with or without fluxes) is to be strongly heated, it should be previously moistened with a little water, just sufficient to hold the powder together and prevent its being blown away before sintering or fusion takes place.

(*b*) *Reduction of Metals.*—Certain metals, notably gold, silver, copper, and lead, may be reduced from some of their minerals without difficulty by heating alone in the R.F. In general, the operation of reduction is considerably facilitated by mixing sodium carbonate, borax, or borax glass (rarely other fluxes are used) and powdered charcoal (scraped from the surface of the charcoal) with the powdered mineral. The charcoal of course acts as a strong reducing agent. The fluxes often act simply as mechanical aids and as absorbers of impurities, but also in some instances react chemically with the substance. In many instances the presence of both the flux and charcoal is necessary in order to obtain a successful reduction. The quantity of flux, etc., required will vary with different minerals and no general statement can be made regarding it. Such details will be given in the text as occasion demands. In any case a quantity of the mineral powder should be taken, such that, when mixed with the flux, moistened with water, and scraped into a compact little mass on the coal, it can be easily covered with the hot reducing part of the flame, otherwise much energy and time may be wasted trying to do something beyond the capacity of the blowpipe flame. In preparing minerals for reduction or decomposition, care should always be taken to grind them *finely*. Generally the "*blue-cone*" reducing flame is used for reductions and decompositions. In certain operations, however, such as, for example, the reduction of the large lead-silver-button in the "silver assay," where it is important to keep the whole mass of the assay entirely in a reducing atmosphere but where very intense heating is not necessary, the "*smoky*" reducing flame is used. (For a list of metallic globules, see table, p. 77.)

EXPERIMENT No. 6.—Try reducing a copper globule from a small fragment of Malachite, $CuCO_3 \cdot Cu(OH)_2$, B.B. in the R.F. Moisten 2 or 3 cmm. of the powdered mineral and reduce. Mix about the same amount with an equal amount of borax, moisten and reduce to a copper globule.

(*c*) *Formation of Sublimates.**—Many minerals yield, either when heated on charcoal B.B. alone or with fluxes, a characteristic sublimate which condenses on the flat surface of the coal at varying distances from the assay, depending on the volatility of the compound deposited and the size of the flame used. The sublimates may result in several ways; the compound may volatilize and deposit unchanged (rare); a volatile oxide may form and deposit (Exp. No. 7); or a reduced metal may itself volatilize B.B., and uniting with oxygen from the air, may settle on the coal (Exp. No. 8); or we may have a combination of the last two processes (Exp. No. 9).

A sublimate should **always** be examined as to its **color,** both when **hot** and **cold**, its distance from the assay, and its **volatility** in **both oxidizing** and **reducing flames** (measured by the ease and rapidity with which the sublimate can be made to disappear from before the flame), and also as to any **coloration** it may impart to the flame.

All charcoal leaves some ash when burned. This ash, which is almost always white, but rarely brown or reddish, forms on the surface of the charcoal block immediately about the assay where the flame strikes the coal. This coating of ash is often mistaken by beginners for a sublimate. It is, however, a very thin coat, retains in some measure a structure derived from the original charcoal, and is non-volatile even on the strongest heating in the R.F. All white oxide sublimates are volatile in the R.F.

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* The "*PLASTER TABLET.*" Where strongly colored sublimates, particularly such as those obtained from certain metals when heated with a mixture of equal parts of potassium iodide and sulphur (see page 83), are to be examined, a plate or tablet made of plaster of Paris is used instead of the charcoal. The colors of the sublimate contrast strongly with the white of the tablet and many striking tests may be obtained in this way. The tablets may be very easily made by pouring plaster of Paris mixed to a rather thin paste with water, over a glass plate, and while still quite soft, dividing the plaster with a knife into little rectangles 1½ in. by 3 in. When hard they can be easily slipped from the glass.

Experiment No. 7.—Heat a fragment of molybdenite, MoS_2, B.B. in the R.F. Next heat a fragment B.B. for some time in a strong O.F. Heat the sublimate last obtained in a mild R.F. (the Bunsen-burner flame answers nicely). Note the colors obtained and that the coating is volatile.

Experiment No. 8.—Mix thoroughly 3 or 4 cmm. of finely powdered cassiterite, SnO_2, with at least one volume of charcoal dust and about two of soda, moisten and heat B.B. in the R.F., remove the globule obtained to a small hole in a clean surface of the coal and heat it strongly in the O.F. Note that the tin itself is volatile.

Experiment No. 9.—Heat a little powdered cerussite, $PbCO_3$, B.B. in the R.F. Test the volatility in O.F. and R.F. Note changes in color on cooling. Moisten the coating formed with a drop of HI solution, and heat gently in a small O.F.

(*d*) *Roasting.*—The term roasting is used to designate the process of removing through oxidation and volatilization one or more constituents of a mineral. These are usually either arsenic, antimony, or sulphur. Where the mineral is not too fusible, the roasting may be most easily accomplished by spreading the fine powder out thinly on a flat charcoal surface and heating it *very* gently in a small oxidizing flame until oxidation is complete. Any fusion of the assay should be avoided if possible, since fusion diminishes the amount of surface exposed and imprisons the element within the fused parts. Toward the end of the operation the heat may generally be increased. With very fusible compounds, such as certain minerals containing antimony, the fused mineral is heated strongly in the oxidizing flame until most of the volatile element is removed. The globule thus obtained is then crushed, spread out on the coal and roasted as first described. The thoroughly roasted product is generally an oxide and, as such, is often in a more suitable form for reduction with fluxes to a metallic globule, for bead tests, etc. Roasting may also be conveniently performed in the open glass tube (see beyond).

Experiment No. 10.—Mix 3 or 4 cmm. of chalcopyrite, $CuFeS_2$, with two volumes of soda and some charcoal and try to reduce a copper globule from it. A brittle, black globule and not metallic copper will be obtained. Next, roast thoroughly about 3 or 4 cmm. of the chalcopyrite as described above. Then mix with equal volumes of soda (or borax) and charcoal as before and reduce to a globule.

Experiment No. 11.—Roast a little niccolite, NiAs, and note the color of the residue.

(*e*) *Decomposition of Insoluble Minerals with Fluxes*.—Minerals, chiefly silicates and oxides, which are slightly or wholly unaffected by treatment with acids may be brought into a condition permitting solution by first fusing them with some flux. This fusion may be performed satisfactorily on charcoal, B.B., or if at hand, a platinum capsule made from a small piece of foil may be used, the Bunsen flame or a blast supplying the heat. A large loop of platinum wire bent back on itself may also be used to support the fusion. This is often the best method to follow where the amount of mineral available is very small. Sodium carbonate (dry) is generally used, but borax or borax glass, potassium bisulphate, or sodium peroxide may be used where soda fails. In general, from five to six volumes of the flux to one of the mineral should be used.

Experiment No. 12.—Carry out an experiment on the decomposition of ilmenite, $FeTiO_3$, with soda as directed under titanium, 1, p. 69.

Experiment No. 13.—Mix thoroughly 4 or 5 cmm. of finely ground garnet with about 5 volumes of sodium carbonate. Moisten to a paste with water and fuse to a slag, heating the assay for several minutes. Crush the resulting fusion and dissolve in about 5 cc. of $6N \cdot HNO_3$ in a test-tube (if charcoal is mixed with fusion it should be filtered off after solution is complete). Finally evaporate the solution in the test-tube until gelatinous silica separates.

Bead Tests.—A limited number of elements, when their compounds are dissolved in fused borax, salt of phosphorus (microcosmic salt), or soda, impart characteristic colors to the flux, which serve to distinguish these elements. The colors observed usually vary more or less with the state of oxidation of the element, so that different colors may be obtained according as the reducing or oxidizing flame is used. The colors also often change as the fusion cools.

In making use of these color reactions a bead of the fused salt is made on a loop of platinum wire. The wire, which should be about No. 28, standard gauge, may be sealed into the end of a short piece of glass tubing to serve as a holder. The loop may conveniently be made by bending the wire about a pencil end. Be sure that the wires touch where the end crosses over. The loop should finally be circular in shape and about 3 mm. in diameter for most bead tests. A larger bead cannot be so easily covered by the reducing flame, while with one much smaller, it is harder to see the color, and the amount of the substance tested is apt to be relatively too large.

Borax and salt of phosphorus may be made to adhere to the loop by simply heating it in the flame, and then, while hot, dipping it into the salt. The borax may be fused without trouble to a transparent, colorless glass. Salt of phosphorus becomes very liquid when first heated, and in order to keep it on the wire, it should be fused just above the blowpipe flame, so that the upward current of hot air from the flame will support it until the volatile part is removed and the bead becomes less liquid. If a Bunsen flame is at hand, the salt of phosphorus bead can be easily made by holding it about one-half inch above the tip of the blue cone. This bead is also clear and colorless when cold. Soda is most easily gotten onto the wire by wetting the loop in the mouth, sticking it into the powdered salt, and then fusing it. This bead is clear when hot, but becomes *white* and *opaque* on cooling.

After the bead is made, it is touched, *while still hot,* to a *minute amount* of the *finely* powdered substance,* and heated successively in the reducing and oxidizing flames of the *blowpipe* (*not the Bunsen burner*). To get the best reducing effect the bead should be heated as hot as possible at the point of the blue cone for a short time, and then by moving the blowpipe back a little, at the same time easing up on the blast, the extremely

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* Where arsenic or antimony are present, it is necessary, in order to prevent the destruction of the platinum wire, to roast the mineral very thoroughly as directed on p. 13 and then test the remaining oxides in the bead. It is also better to roast sulphides previous to testing in the bead.

hot bead may be entirely *covered* for a time by the "smoky" (carbon rich) reducing flame. In oxidizing a bead it should be heated for several minutes, since the oxidizing flame is not as hot as the reducing flame, and the reaction generally takes a longer time. In general, it is best to start with a very small speck of the "unknown," and then increase the amount gradually until enough is dissolved in the bead to give a decisive color. The heating in both flames should *always* be repeated, so as to be sure that the color or colors are constant, and care should be taken to watch for a change of color while the bead is cooling, and until it is perfectly cold. When a bead is obtained which is too dark to show the color distinctly, its true color by transmitted light may be seen by crushing the bead and noting the color of the powder.

A list of "bead" reactions will be found on pages 83–85. This includes only such as experience has shown to be perfectly reliable in the hands of the average manipulator, provided the suggestions made above are followed. Many of the "bead" tests given in the more extended lists to be found in other texts are of very doubtful value. The following experiments will illustrate several of the more important bead reactions. It may be remarked that "bead" tests are often particularly useful as confirmatory tests with minerals, and with final precipitates, especially small ones obtained in the course of a qualitative analysis.

Experiment No. 14.—Introduce a very little of powdered pyrolusite, MnO_2, into a borax bead and heat B.B., first in the hottest part of the flame, until the mineral is entirely dissolved, then in the O.F. Note the color when cold. Next heat it as hot as possible in the clear R.F. for a short time, and then cover the bead with the smoky R.F. The bead should be colorless on cooling.

Experiment No. 15.—Make a salt of phosphorus bead test with vanadinite, lead vanadate, using a small amount of the salt first and then increasing it. Use both O.F. and R.F. Make similar tests with wulfenite, $PbMoO_4$, and chromite, $FeCr_2O_4$.

Heating in the Closed Glass Tube.—Tubes, closed on one end, are made by first heating a piece of thin-walled, hard glass tubing, of twice the required length, in the middle, in a blast lamp or good Bunsen flame. When quite soft it is taken out of the flame, pulled out, and the capillary ends of each half nicely sealed off close up to the end. The tubes should, for most purposes, be from 3 to 4 mm. internal diameter and about 8 cm. long.

Closed tubes (C.T.) are used chiefly to ascertain whether or not a substance is decomposed or changed in any way by heat alone. They are occasionally used in making fusions with fluxes, and then a tube of larger diameter is desirable, or sometimes one with a small bulb blown on the end is used.

In closed tube tests a few small fragments, say a millimeter in diameter, or with very refractory materials a little of the powder, are shaken down into the end of the tube, which is heated somewhat gradually to the full heat of a Bunsen flame, or to that of the blowpipe flame, where the former fails to produce any change.

Decomposition may be indicated by a change of color in the material, or by the formation of a sublimate, solid or liquid, or by a vapor in the cooler part of the tube. A full list of closed tube reactions will be found on pages 78–79.

Substances which decrepitate may be heated in the C.T. until decrepitation ceases and the resulting powder may then be safely tested on charcoal.

The amount of oxygen contained in the tube is so small that its action is, in general, negligible, although in a few instances, such as with the antimony-sulphur minerals, its action is important.

Experiment No. 16.—(*a*) Heat a fragment of siderite, $FeCO_3$, in a closed tube. Note the change of color and test the residue with a magnet. If a drop of barium hydroxide be put in the upper part of the tube before heating, a white precipitate of barium carbonate will be formed in the drop by the absorption of the CO_2 given off by the carbonate. This is a general reaction with carbonates. (*b*) Next, heat fragments of malachite, $CuCO_3 \cdot Cu(OH)_2$ (blackening of residue and sublimate of water). (*c*) Heat a few fragments of gypsum, $CaSO_4 \cdot 2H_2O$, in a closed tube. Do the same with brucite, $Mg(OH)_2$. Compare the relative amount of heating required in each case to expel the water. In the first case the water is "water of crystallization," that is, water taken on during the crystallization of the substance. In the second, the water is chemically combined and is therefore "water of composition," or "hydroxyl." (*d*) Heat fragments of pyrite, FeS_2, and arsenopyrite, FeAsS, separately in closed tubes. In each case, after thorough heating, break off the end of the tube by touching it, while still hot, with a drop of water, and test the residue with a magnet.

The reactions taking place in each case are shown by the following equations:

(*a*) $FeCO_3 = FeO + CO_2$.
(*b*) $CuCO_3 \cdot Cu(OH)_2 = 2CuO + CO_2 + H_2O$.
(*c*) $CaSO_4 \cdot 2H_2O = CaSO_4 + 2H_2O$.
$Mg(OH)_2 = MgO + H_2O$.
(*d*) $FeS_2 = FeS + S$.
$FeAsS = FeS + As$.

Heating in the Open Glass Tube.—The " open tube " (O.T.) is a hard glass tube, from 15 to 17 cm. long, with an internal diameter of from 5 to 7 mm. The substance to be heated in the tube should in general be powdered, and is placed some 4 or 5 cm. from one end. A neat and convenient way of getting the powder into the tube is to put it in the end of a small V-shaped piece of paper which is then introduced into the tube and turned over. By this means the powder is all deposited in a single small heap. 4 or 5 cmm. of material is usually amply sufficient, and exceedingly small amounts may often, with care, be made to yield decisive results.

The tube, held in an inclined position (say 20°), is heated in the Bunsen flame, *first above the assay*, so as to start a good current of air through the tube. If the tube softens, it may be bent a little, thus making it easier to keep the powder from slipping out. The assay is next heated intermittently and *very gently* for some time, then more and more steadily to the full heat of the flame. When very volatile substances are given off, HgS or As, for example, very slow and cautious heating may be necessary throughout the test. If the mineral thus heated in contact with a current of air contains an element which forms a volatile oxide, the latter will either pass out of the end of the tube, where, as in the case of sulphur, it may be detected by its odor, or it may condense as a sublimate with a characteristic appearance on the cooler parts of the tube. A sublimate, if desired, may be collected and tested further. If the heating or "roasting" is continued long enough, a residue of metallic oxide or oxides usually results, and this, if it possesses no characteristic appearance to identify it, is in a favorable condition for examination by means of bead tests or otherwise.

For a list of Open Tube Reactions, see pp. 79–81. The following tests will serve to illustrate open tube reactions:

Experiment No. 17.—Heat a little powdered galena, PbS, in the open tube as directed above. Notice that the SO_2 is given off at the end of the tube and the lead is oxidized to lead oxide, PbO, which is deep yellow when hot, fading out to nearly white on cooling ($PbS+3\,O=PbO+SO_2$). If heated rapidly, PbO and SO_2 combine to form some volatile white compound, which condenses on the under side of the tube. Another reaction may occur, to a slight extent, as follows: $PbO+SO_2=Pb+SO_3$, resulting in tiny globules of lead.

Experiment No. 18.—Heat in an O.T. a little powdered niccolite, $NiAs$. Examine the crystalline sublimate with a lens.

Experiment No. 19.—Do the same with arsenopyrite, $FeAsS$, heating very slowly and cautiously.

Flame Tests.—As has been noted earlier, flame colorations may be obtained from a number of minerals by simply heating a fragment B.B. While the flame colors thus obtained are often strong enough to be decisive tests there is quite as often some uncertainty about them. A number of minerals which do not yield a flame color in this way can be made to yield good flames by one of the following methods:

(1) *Heating on a Fine Platinum Wire.*—A fine and perfectly clean platinum wire is moistened in water and dipped lightly in a bit of the very finely powdered mineral. The wire with a little adhering powder is then heated in the edge of the Bunsen flame, about 2 cm. above the end of the tube. By using hydrochloric acid or, less commonly, sulphuric acid (the latter with phosphates) in place of water the flame color may be greatly intensified. This is particularly true of calcium, strontium, barium, and copper.

(2) *By Injecting Some of the Fine Powder into the Bunsen Flame.*—This may be most easily accomplished by holding the steel mortar, in which the mineral is powdered, close to the air hole near the base of the Bunsen burner, and puffing a little of the fine dust into the hole by pushing the pestle suddenly into the mortar; or the fine powder may be blown into the hole, or directly into the flame, by a jet of air from the blowpipe directed across a bit of paper on which some of the powder has been placed.

Treatment with Acids,* etc.—In testing minerals in the wet way it is generally most convenient to use a test-tube. Usually about 0.1 to 0.2 gram of the *finely* ground mineral may be recommended, while the amount of acid or other solvent should not, in general, exceed 5 to 10 cc. Where it is found necessary to use larger quantities, the operations are better carried on in a small casserole.

Although few minerals are appreciably dissolved by water alone, it is well, if the mineral is soft, to test its solubility in water. The great majority of solubility tests are performed with dilute hydrochloric or nitric acid, or both successively. If no action is noted with cold acid, the tube is heated gradually to boiling.

If the mineral goes into solution with the evolution of a gas, the latter is usually carbon dioxide, CO_2, but it may be hydrogen sulphide, H_2S, chlorine or an oxide of nitrogen. H_2S may be recognized by its characteristic odor, or tested for by holding a piece of filter paper moistened with lead acetate solution in the end of the test-tube (blackens). Chlorine may also be recognized by its odor and by its bleaching action on moistened litmus paper. Oxides of nitrogen appear as brown fumes (dioxide) above the surface of the liquid. To test for CO_2, see p. 34.

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* More experiments can of course be carried out to illustrate the tests described under the various headings of this chapter if it is felt desirable to do so. It has long been the practice of the author to make the preliminary work as brief as possible, using it only to introduce the student to the type tests. Later an abundance of tests are carried out in connection with the study of the various mineral species. By this procedure the tests have a direct and obvious purpose and the work is rendered more interesting, and has a greater instructional value, besides affording adequate practice in manipulation.

CO_2 indicates a *carbonate;* H_2S, a *sulphide;* chlorine some higher oxide of *manganese;* oxides of nitrogen point to an oxidizing action, such as results from the action of nitric acid on a metal or metallic sulphide. Care should be taken not to confuse the bubbling of the solution due to boiling, with effervescence proper. On taking the tube out of the flame boiling ceases almost immediately, while effervescence continues for some moments.

If the mineral passes into solution **without effervescence,** the solution should be evaporated nearly to dryness to see if gelatinous silica will separate. In order to carry the silica test further, see p. 57.

If the mineral is non-metallic in character, and it is suspected, either because the color of the acid or the appearance of the powder has changed, that the mineral has decomposed with the separation of an insoluble residue (usually silica), the solution may be filtered off and tested for bases with appropriate reagents. See p. 58, § 4.

Few metallic or submetallic minerals that are appreciably soluble in dilute acids yield a residue, and need not be considered here.

Metallic or **submetallic** minerals, when unaffected by treatment with dilute acids, should be treated with strong nitric acid (Sp.G. 1.42) and heated. With metals, or compounds of the metals, containing sulphur, arsenic, or antimony, oxidation accompanied by solution, or the formation of an insoluble compound, or by both, results, and reddish-brown fumes of nitric oxide are given off. For a list of residues that may be obtained by such treatment, also for colors imparted to solutions by certain metals, see p. 88.

When the mineral is found to be nearly or wholly insoluble, it may usually be obtained in solution by fusion (see p. 14) and subsequent treatment of the fusion with acids.

CHAPTER II

SIMPLE TESTS FOR THE ELEMENTS

For convenience in the matter of reference the elements will be taken up in alphabetical order. The atomic weight of each element is given after the name.

Aluminium, Al—27.1

1. *Test with Cobalt Nitrate.*—This test is applicable *only* to those minerals which are *infusible* and *white*, or which become white on ignition. The fragment or powder moistened with cobalt nitrate solution and *intensely* ignited for some time B.B. assumes a fine blue color.

Fusible minerals and fluxes, when moistened with cobalt nitrate and ignited, often assume a blue color, whether aluminium is present or not, and cannot therefore be tested for aluminium in this way.

Silicate of zinc, calamine, when treated similarly assumes a blue color (see page 86), which should not be mistaken for an indication of aluminium.

2. *Precipitation with Ammonium Hydroxide.*—Aluminium hydroxide, $Al(OH)_3$, is thrown down from solutions of aluminium salts by the addition of a slight excess of ammonium hydroxide. As several other substances are also thrown down by ammonium hydroxide in a form which often resembles the aluminium precipitate, the following additional test should be made. The precipitate, collected on a filter, is washed with water, and after removing it to a test-tube, is warmed with a few cc. of a solution of potassium hydroxide. Aluminium hydroxide, if present, will dissolve easily and may be filtered away from the other substances, except beryllium, that may have precipitated. The presence

of aluminium is proved by adding ammonium hydroxide to the filtrate, after it has been *acidified* with hydrochloric acid. The reprecipitated aluminium hydroxide may be further tested by igniting it on charcoal, after moistening it with cobalt nitrate.

To detect aluminium in insoluble silicates, where the above methods cannot be directly applied, see page 59.

Antimony, Sb—120.2

1. *Flame Test.*—Antimony compounds when heated in the R.F. impart a pale greenish color to the flame, owing to the volatilization of metallic antimony. (Care should be taken not to alloy the platinum forceps when heating antimony or its compounds.)

2. *Heating on Charcoal.*—Antimony and its compounds, with the exception of a few oxides, yield, when heated in the O.F., a dense white sublimate of oxide of antimony, which deposits at a short distance from the assay and has a bluish appearance on its edges. It is *completely volatile* in both the O.F. and R.F., and has no distinctive odor.

When soda is used as flux with antimony minerals, small gray, metallic globules of antimony are sometimes obtained in the R.F. They are brittle.

In the presence of other elements, which also yield sublimates on charcoal, the coating is not decisive, and confirmatory tests must be made, preferably the *open tube* test. Especial care should be taken not to mistake the coating which is formed when galena, PbS, is heated rapidly on charcoal B.B., for that of antimony. This coating is in part due to some combination of PbO and SO_2 and is apt to deceive beginners. When heated very slowly in the O.F. galena does not give this coating. See lead, p. 44.

For a few compounds of antimony which are not volatile, the R.F. must be used first to reduce the antimony before volatilization can take place.

3. *Iodine Test on the Plaster Tablet.*—The antimony subli-

mate, collected on a plaster tablet, if moistened with a drop of hydriodic acid and heated gently B.B., assumes an orange color mixed with peach-red. The same result may be obtained by fusing the mineral with a flux composed of equal parts KI and S. On charcoal the iodide coating is a faint yellow.

4. *Test in the Open Tube.*—Antimony and its compounds, with the exception of a few oxides, when heated in the open tube yield a white sublimate of antimony oxide or oxides.

When sulphur is present, the sublimate usually takes the form of a dense white smoke, the greater part of which settles along the under side of the tube, while a part deposits as a white ring not far from the heated part. The ring, when examined with a lens, is often found to consist of two forms (octahedrons and prisms) of crystallized antimony trioxide, Sb_2O_3. It is volatile and can be slowly driven out completely. (Compare arsenic, p. 25.) The dense white sublimate on the under side of the tube has the composition Sb_2O_4, is *non-volatile*, infusible, and becomes yellow when heated, but turns white again on cooling. The sulphur, when present, in some way causes the formation of the oxide, Sb_2O_4, along with Sb_2O_3. *Metallic antimony*, and a *few minerals* containing sulphur, yield the trioxide alone.

5. *Closed Tube Test.*—Sulphide of antimony, and many compounds containing antimony and sulphur, when heated intensely in the closed tube, yield a sublimate, which is black when hot, but is red or reddish-brown when cold. It is the oxysulphide of antimony, Sb_2S_2O, and its formation is one of the few closed-tube reactions in which the small amount of oxygen in the tube plays an important part.

Metallic antimony is not volatile when heated in the closed tube, except at a very high temperature, viz., that at which hard glass melts. This difference in behavior from that of metallic arsenic (see p. 25), which is easily volatile, should noted.

6. *Oxidation with Nitric Acid.*—Nitric acid oxidizes antimony and its compounds, forming a white compound, metantimonic acid, SbO_2OH(?). This is very insoluble in nitric acid and water, and when filtered from the solution after the latter has been

diluted with water, gives a fairly good separation of antimony from elements which are often associated with it, especially from small quantities of arsenic. The material on the filter paper may then be examined B.B. on charcoal for antimony.

Arsenic, As—75

A. TESTS FOR ARSENIC IN MINERALS CONTAINING NO OXYGEN.

1. *Flame Test.*—When arsenic minerals are heated B.B. in the R.F. the arsenic is volatilized, and imparts a pale violet color to the flame.

2. *Roasting on Charcoal.*—Arsenic, or its compounds with sulphur and the metals, when heated on charcoal in the O.F. form volatile products, which oxidize to arsenic trioxide, As_2O_3, and deposit on the charcoal at a **considerable distance** (compare antimony) from the assay as a *white and extremely volatile* sublimate. When the R.F. is used a disagreeable *garlic-like* odor is usually obtained from the fumes which are given off. This odor is very characteristic, and a minute quantity of arsenic may be detected by means of it. The odor is probably due to the presence of finely divided particles of arsenic.

3. *Roasting in the Open Tube.*—When arsenic, or one of its compounds with sulphur or the metals, is heated *very slowly* in the open tube, a white crystalline sublimate of arsenic trioxide, As_2O_3, is obtained in the form of a ring on the sides of the tube. The sublimate is *very* volatile, and can be entirely driven out of the tube with heat (compare antimony). The fumes of As_2O_3 have *no odor*. On examining the sublimate with a lens it will be found to consist of octahedral crystals, which are occasionally twinned.

Some arsenides, like arsenopyrite, FeAsS, which gives off its arsenic readily, if heated otherwise than very slowly, yield, with the white oxide, a yellow sublimate of sulphide of arsenic, or a black one of arsenic. This is because the amount of oxygen is insufficient to completely oxidize the rapidly volatilizing arsenic.

4. *Heating in the Closed Tube.*—Arsenic is completely volatilized when heated in the closed tube, and deposits on the walls of the tube. A small amount appears as a brilliant black ring while a larger amount appears gray and crystalline in the part of the ring nearest the heated end. *Some arsenides* are decomposed in the closed tube, and give this same mirror.

If the tube is broken just below the sublimate, and heated so that the arsenic is volatilized, the garlic odor may be obtained, which will distinguish it from other black sublimates.

5. *Special Test for Oxide of Arsenic.*—Where antimony is present with a little arsenic in a mineral it may be impossible to tell surely from the sublimate obtained on charcoal, or in the O.T., whether arsenic is present or not. In such case the arsenic may be detected by putting the oxides obtained in the O.T., or on charcoal, in the bottom of a closed tube, with a splinter of charcoal just above it. (It is well to draw the closed end of the tube out somewhat smaller than usual.) Heat the splinter until it becomes red hot, and then slowly heat the oxide, which is volatilized, and in passing over the coal is reduced, and deposits as an arsenical mirror beyond the splinter. This test is an exceedingly delicate one.

6. *Oxidation with Nitric Acid.*—Concentrated nitric acid oxidizes and dissolves most arsenides with the formation of arsenic acid, H_3AsO_4, which may be detected by the methods given under B, § 3.

B. DETECTION OF ARSENIC IN MINERALS CONTAINING OXYGEN (THE NATURAL ARSENATES).

1. *Heating in the R.F. on Charcoal.*—By intense ignition B.B. in the R.F. the arsenates are reduced, yielding arsenic, which usually gives the characteristic garlic odor, and yields a sublimate of As_2O_3 on the charcoal.

2. (*a*) *Reduction in the Closed Tube.*—All fusible arsenates may be tested as follows: Put a fragment or two of the mineral in a small closed tube with a few *splinters* of charcoal, and heat

intensely B.B., when the arsenate will be reduced and an arsenical ring or mirror formed. The mirror may be tested by breaking the tube below it, and noting the garlic odor when it is heated.

(*b*) If the arsenate is infusible (which is seldom the case), and easily reducible metals, like copper, lead, and iron are absent, the powdered mineral should be mixed with about four volumes of *dried* sodium carbonate and a little charcoal dust, and heated *gradually* B.B. to an intense heat. Reduction will take place and an arsenic mirror will be formed.

(3) *Precipitation as Ammonium Magnesium Arsenate.*—If it is found that the above tests cannot be used, the following test in the wet way may be made: Fuse the powdered mineral with about six volumes of sodium carbonate on charcoal in the O.F. Soak out the sodium arsenate thus formed, in a test tube, by boiling for a minute with water, filter, acidify the filtrate with an excess of hydrochloric acid, then add an excess of ammonia (this may cause the precipitation of a little arsenate) and then a little magnesium sulphate. The arsenic, if present, will be precipitated as ammonium magnesium arsenate, NH_4MgAsO_4. This may be dried and tested as directed under (2*b*). In case of a very small amount of precipitate, the filter paper may be charred by gentle ignition in a porcelain crucible, and the residue tested as above.

Barium, Ba—137.4

1. *Flame Test.*—Barium minerals, with the exception of a few rare silicates, impart a *yellowish-green* coloration to the flame. The color should not be confused with that yielded by boron or phosphorus. The flame may be advantageously examined with the spectroscope.

2. *Alkaline Reaction.*—Like other minerals containing alkali or alkali earth metals, those of barium, with the exception of the silicates and phosphates, give an alkaline reaction when placed on moistened litmus or turmeric paper, after being strongly ignited B.B.

3. *Precipitation as Barium Sulphate.*—Barium is completely precipitated from solutions of its salts, by the addition of sulphuric acid, as a white, heavy precipitate of barium sulphate, $BaSO_4$. Insoluble minerals must first be fused with about five volumes of sodium carbonate, and, after the sodium sulphate thus formed has been thoroughly leached out by treatment with hot water, the barium carbonate may be dissolved in hydrochloric acid and the sulphate test applied. The precipitated sulphate may be collected on a filter, washed, and tested for the flame color by introducing a little of it on a platinum wire into the Bunsen flame.

Beryllium, Be—9.1

Beryllium, sometimes called glucinium, Gl, is a comparatively rare element, occurring in only a few minerals, the most common one being the silicate of beryllium and aluminium, beryl. There are no satisfactory blowpipe tests for the element, and it must be tested for by wet methods. The following tests, if executed carefully, will be found adequate for testing beryllium minerals. If a silicate, the mineral must be decomposed by fusion with sodium carbonate, preferably in a small platinum or porcelain capsule. The fusion is treated to remove silica, as directed on p. 58. Ammonia is added to the filtrate from the silica, and the resulting precipitate, which resembles aluminium hydroxide in appearance, is washed thoroughly with water. The precipitate and filter are warmed in a small beaker with hydrochloric acid and filtered into a small casserole to remove the paper. The solution is evaporated to a volume of two or three drops, cooled, a few drops of water are added to effect complete solution, and then a little potassium hydroxide solution is added, a few drops at a time, until the precipitate of beryllium hydroxide, which forms, is just dissolved. The solution is then diluted with 50 to 100 cc. of cold water, any precipitate of ferric hydroxide is filtered off, and the liquid boiled for a short time. If beryllium is present it will now precipitate as the hydroxide (aluminium remains dissolved).

If a phosphate is to be tested, it must be dissolved in a few cc. of hydrochloric acid (after fusion with sodium carbonate, if insoluble). Ammonia is then added to the cold solution until a permanent precipitate forms. This is then just redissolved by adding hydrochloric acid, very cautiously, a drop at a time. To this neutral solution, which should be cold, sodium acetate is added. Beryllium phosphate is precipitated, and is filtered and washed. As this may be mixed with calcium and aluminium phosphate, the precipitate is ignited in a crucible to burn off the paper, and fused in platinum with sodium carbonate. The sodium phosphate formed is soaked out with hot water, and removed from the beryllium oxide by filtration and washing. The beryllium is then dissolved in hydrochloric acid, and treated with potassium hydroxide, as described in the paragraph above.

If beryllium hydroxide is ignited on charcoal with cobalt nitrate solution a lavender color is said to result.

Bismuth, Bi—208

1. *Reduction to Metallic Bismuth on Charcoal, and the Formation of a Coating of Bismuth Oxide.*—Globules of metallic bismuth may be obtained if the finely powdered bismuth mineral is mixed with about three volumes of sodium carbonate and heated B.B. in the R.F. The globules are bright while in the R.F., but quickly tarnish to a dull gray on exposure to the air. When cold they are rather brittle and *break to pieces* when hammered, instead of flattening to a thin sheet, like lead. B.B. bismuth is somewhat volatile. In this state it unites with oxygen from the air, forms bismuth oxide, Bi_2O_3, which deposits on the charcoal near the assay as a deep orange-yellow coating when hot, fading to a lighter shade on cooling. The oxide is volatile in both the O.F. and R.F. The coatings of lead and bismuth oxides are quite similar, but may be distinguished by the iodine test (§ 2, below).

2. *Iodine Test.*—The coating of oxide, obtained as above, is moistened with a drop or two of hydriodic acid and heated gently

with a small O.F. A coating will be formed which is yellow near the assay, but bordered on the outer edges with red or brownish-red. The same result may be obtained by heating gently, with a small oxidizing flame, a small amount of the mineral with three or four volumes of a mixture of equal parts, potassium iodide and sulphur.[1]

If a plaster tablet (see page 12) is used instead of charcoal, a chocolate-brown coating of bismuth iodide is obtained, which turns to a brilliant red if held in the fumes of strong ammonia for a short time.

3. *Wet Tests.*—The hydrochloric acid solution of the mineral is evaporated until only a few drops remain. These are poured into a test-tube half full of cold water, when a white precipitate of bismuth oxychloride is formed. This may be filtered off and tested B.B. on charcoal. If the mineral is insoluble in hydrochloric acid, the nitric acid solution may be evaporated with an excess of hydrochloric acid, until no nitric acid remains.

Lead may be separated from the bismuth as follows: Dissolve in conc. nitric acid, cool, add 2 or 3 cc. of concentrated sulphuric acid, and evaporate until the nitric acid is expelled and dense white fumes of sulphuric acid appear. Cool and pour into 10 cc. of water, rinsing out the tube or dish with a little cold water. Stir and allow to stand for five minutes. Filter off the precipitated lead sulphate, which may be tested on charcoal B.B. by 3, p. 45. To the filtrate add $6N \cdot NH_4OH$ in excess, which will precipitate $Bi(OH)_3$, if any bismuth is present. Filter, and dissolve the precipitate in HCl. Concentrate this solution, and pour into a large amount (100 cc.) of water; a white precipitate of BiOCl will indicate bismuth. This precipitate may be further tested by collecting on a filter and pouring on it a solution of freshly prepared sodium stannite. If the precipitate was BiOCl, a black residue of metallic bismuth will be formed. The sodium stannite is prepared by taking a few drops of $SnCl_2$, diluting with 5 cc. of water and adding NaOH solution, a few drops at a time,

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[1] This mixture is known as "Bismuth Flux."

until the precipitate of $Sn(OH)_2$, which forms first, just redissolves.

Boron, B—11

1. *Flame Test.*—Many boron minerals when heated alone B.B. impart a bright green color to the flame. The green is inclined somewhat to yellow (siskin green), and must not be confused with the green of barium and phosphorus.

Minerals which do not give the boron flame directly may be mixed with about three volumes of a mixture of equal parts calcium fluoride (fluorite) and acid potassium sulphate, and introduced into the Bunsen flame on a platinum wire. A green flame, of momentary duration, will be seen if boron is present. In this reaction the calcium fluoride, CaF_2, and the acid potassium sulphate, $HKSO_4$, react to form hydrofluoric acid, HF, which attacks the mineral, forming the fluoride of boron, BF_3, which is a very volatile salt of boron, and gives the characteristic flame coloration.

2. *Turmeric-paper Test.*—A piece of turmeric paper is moistened in a dilute hydrochloric acid solution of the mineral to be tested, and dried at 100° C. on the outside of the test-tube containing the boiling solution. If boron is present the paper assumes a reddish-brown color, which is changed to an inky-black by moistening with ammonia. This is a very delicate test. If the mineral is insoluble in acids it must be first fused with sodium carbonate, as directed on p. 14, and then dissolved.

Bromine, Br—79.9

When a bromide is heated in a large closed or bulb tube with acid potassium sulphate and pyrolusite (manganese dioxide,) bromine is liberated as a red vapor, which condenses to a red liquid if much is present. Iodine and chlorine are liberated from iodides and chlorides respectively in the same way, so that in order to distinguish these elements surely in the presence of each other, more elaborate wet methods must be used. For these, the student is referred to Brush and Penfield's "Determinative Mineralogy," etc., page 69, or to works on qualitative analysis.

Silver bromide, which is the only important compound of bromine found as a mineral, if heated in a closed tube with galena, PbS, yields a sublimate of lead bromide, PbBr. This is sulphur yellow when hot and white when cold. Iodide of silver, if present, as it often is in nature, may lead to confusion. (See reference given above for wet tests.)

Cadmium, Cd—112.4

Cadmium minerals when heated B.B. in the R.F., after mixing with sodium carbonate, yield a reddish-brown coating of cadmium oxide, which is yellowish, distant from the assay. It is usually iridescent if only a little forms. As cadmium occurs in certain zinc minerals, this coating may be noticed just before the zinc oxide begins to deposit when such minerals are heated B.B. It is, however, best to test for cadmium by the regular wet analytical methods. It may be separated from zinc by precipitating it, as the yellow sulphide, with hydrogen sulphide in a cold solution of its sulphate which has present, beside a little free sulphuric, about 10 cc. of dilute hydrochloric acid, in a final volume of about 100 cc.

Calcium, Ca—40

1. *Flame Test.*—Some calcium minerals impart a yellowish-red color to the flame. This flame is much stronger if the fragment or powder is moistened with hydrochloric acid. In neither case is the test sufficiently characteristic to be decisive, and spectroscopic or other confirmatory tests must be made. The flame must not be mistaken for that of strontium, which has a brilliant crimson color. It should be remarked, that if a little sodium is present on the mineral specimen, a strontium flame may appear yellowish and be mistaken for that of calcium.

2. *Alkaline Reaction on Test Paper.*—With the exception of the silicates, phosphates, borates, and the salts of a few rare acids,

calcium minerals give an alkaline reaction when placed on moistened turmeric or litmus paper after strong ignition B.B.

3. *Precipitation as Calcium Sulphate.*—Calcium forms a sulphate which is sparingly soluble in water and hydrochloric acid. Accordingly, this sulphate may be thrown down from not too dilute, nor too strongly acid solutions, by the addition of sulphuric acid, and, if carried out as directed beyond, is a very characteristic test. The solution to be tested should be freed, by evaporation if necessary, of all but a very little free hydrochloric or nitric acid, and should contain only enough water to keep the salts entirely in solution. A few drops of dilute sulphuric acid will produce in such a solution, if calcium is present, a white, feathery precipitate of the hydrated calcium sulphate, $CaSO_4 \cdot 2H_2O$. If much calcium is present it will be thick and curdy. This precipitate may be readily dissolved upon the addition of water, and warming, and this behavior distinguishes calcium from barium and strontium sulphates. If the solution in which calcium is to be tested for is divided into two parts, and one diluted with about ten volumes of water, it will be found, that upon the addition of sulphuric acid to both, a precipitate will form only in the portion which was not diluted.

4. *Behavior with Ammonia.*—Calcium is not precipitated from its solutions by ammonium hydroxide, *except* when acids are present which form with calcium, under such conditions, an insoluble compound. The most important of these acids with which calcium is commonly found in nature are carbonic, phosphoric, silicic, and boric acids. This *important behavior should be carefully borne in mind while testing solutions of minerals with ammonia.* Carbonic acid is quickly removed from the solution by boiling, so that no precipitate is formed in boiled solutions obtained from carbonates, and test § 5 or § 6 may be used; when the other acids are present, § 3 may be used.

5. *Precipitation as Ammonium Oxalate.*—Ammonium oxalate produces in alkaline and even slightly acid solutions of calcium salts a complete precipitation of calcium as the oxalate, CaC_2O_4. If it is desired to remove the precipitate from the solution, it will

be found best to make the precipitation in a boiling hot solution, and to continue the boiling for a minute or so, before any attempt is made to filter it.

6. *For the detection of calcium in silicates and other complex minerals,* see page 58, § 4.

Carbon, C—12

A. 1. *Bituminous Coals, Hydrocarbons, and Organic Matter. Closed Tube Reactions.*—If the above substances are heated in the closed tube, tarry matters, oils, gases, and water are given off and distill up the tube. A peculiar "empyreumatic" odor is usually observed. If the tube is drawn out to a capillary at the open end, the more volatile products of the distillation may be lighted with a match. The residue is usually nearly pure carbon.

2. *Anthracite Coals and Graphite.*—These two forms of carbon yield little or no volatile matter when heated in the closed tube. They may, however, be tested in the closed tube as follows: Put a number of splinters of pyrolusite, manganese dioxide, in the bottom of a closed tube (a bulb tube is better if at hand) and above it a small piece of the material to be tested. Heat the substance to redness, at the same time heating the pyrolusite. The latter will give off oxygen, which will cause the fragment to burn if it consists of carbon.

B. 1. *Carbonates; Effervescence with Acids.*—Carbonic acid is liberated when a carbonate is dissolved in one of the strong mineral acids (HCl, HNO_3, H_2SO_4), and as it breaks down into water and carbon dioxide ($H_2CO_3 = H_2O + CO_2$) the latter escapes from the solution with bubbling (*effervescence*). It is best to use dilute acids, since concentrated ones sometimes prevent or hinder solution (with cerussite, $PbCO_3$, for example). Although some carbonates effervesce in cold acids, many require the application of heat to effect solution, so that in testing a carbonate, the solution should always be heated if it does not effervesce when cold.

When heating is resorted to, care should be taken not to mistake the escape of steam bubbles during boiling for effervescence.

Calcite and aragonite ($CaCO_3$) effervesce freely in very dilute HCl or HNO_3, or in the weaker acids, acetic and citric, and this fact serves as a ready means of distinguishing these minerals from other common ones.

Since carbon dioxide is a colorless, odorless gas it is easily distinguished from the other gases, H_2S, Cl, NO_2, which may be encountered in testing minerals. Carbon dioxide may be identified by pouring the heavy gas, which has collected in the test-tube, into another tube containing a few cc. of a solution of barium hydroxide. The tube is then closed with the thumb and shaken, when, if CO_2 is present, a white precipitate of barium carbonate will form.

2. *Decomposition in the Closed Tube.*—Most carbonates are decomposed by heating in the closed tube with the evolution of carbon dioxide. Some are decomposed easily, like iron carbonate; others, like calcium carbonate, require a rather high temperature. By introducing a drop of barium hydroxide solution into the mouth of the tube with a pipette the presence of carbon dioxide will be indicated by the formation of a white precipitate of barium carbonate.

Cerium, Ce—140.2 (see under Rare Earths)

Chlorine, Cl—35.5

1. *Precipitation as Silver Chloride.*—Silver nitrate, added to the aqueous or nitric acid solution of a chloride, produces a precipitate of silver chloride, AgCl. If only a little of the chloride is present the silver nitrate causes only an opalescent turbidity; if more, the precipitate is white and curdy. On exposure to the light it turns purple. Bromine and iodine likewise form precipitates with silver nitrate. For methods dealing with the separation of these elements, see Brush and Penfield's "Blowpipe Analysis," page 69, or standard works in analytical chemistry.

Where the mineral containing the chloride is insoluble, it must first be fused with sodium carbonate, the fusion soaked out with water, acidified with nitric acid, filtered if necessary, and silver nitrate then added.

2. *Evolution of Chlorine.*—If the powdered chloride is mixed with about four volumes of potassium bisulphate and a little pyrolusite (manganese dioxide), and heated in a small test-tube, or better, a bulb tube, chlorine gas will be given off. This may be recognized by its pungent odor and the fact that it will bleach a piece of litmus paper held in the end of the tube.

Insoluble chlorides must first be fused with sodium carbonate, the fusion pulverized, and then treated as above.

Chromium, Cr—52.0

1. *Bead Tests.*—The bead tests are very characteristic and afford a satisfactory method of detecting chromium in its minerals. The intensity of the various colors given in the accompanying table depends on the relative amount of powder used, but the colors are distinctive even when very little material is used.

		SALT OF PHOSPHORUS	BORAX
Oxidizing Flame	HOT	Dirty Green	Decided Yellow
	COLD	Fine Green	Fine Yellowish-Green
Reducing Flame	HOT	Same as in O.F.	Fine Green
	COLD	Same as in O.F.	Fine Green

Where small quantities of chromium are associated with other substances which color the fluxes, the following method is recommended:

2. *Precipitation as Lead Chromate.*—If the mineral is a silicate

it may be decomposed by fusing with a mixture of four parts sodium carbonate and two of potassium nitrate, in a platinum spoon or crucible. If the mineral is an oxide and difficult to decompose, a large borax bead may be saturated with the mineral, and this bead crushed and fused with two or three volumes of sodium carbonate and one of potassium nitrate. Where *sodium peroxide* is at hand, the above decompositions are best made by fusing with that reagent. Whichever one of these fluxes is used, a soluble alkali chromate is formed. This is soaked out in about 5 cc. of water, the solution filtered (the filtrate is yellow if chromium is present), slightly acidified with acetic acid, filtered again if necessary, and any chromium present thrown down as a yellow precipitate of lead chromate by adding some lead acetate to the solution. This precipitate may be collected on a small filter and tested in the bead according to § 1.

Cobalt—58.9

1. *Bead Tests.*—Oxide of cobalt imparts a deep blue color to both the borax and salt of phosphorus beads. This is an extremely delicate test and even serves to identify small amounts of cobalt when comparatively large quantities of iron and nickel are present.

When copper and nickel are present in quantity, and it is desired to test for cobalt, the borax bead may be removed from the wire and heated in a strong R.F. on charcoal, until copper and nickel are reduced to the metallic state, when the borax will show the blue of cobalt.

2. *Nitric Acid Solutions* of minerals which contain considerable cobalt are colored *rose-red.* The addition of an excess of ammonia turns the solution brown. On standing this becomes red.

3. *Test for Cobalt in the Presence of Nickel.*—Small amounts of cobalt in the presence of nickel may be detected as follows: To a little of the powdered mineral in a small test-tube, a cubic centimeter of conc. HNO_3 (1.42 Sp. G.) is added. After being

allowed to stand for several minutes, a few drops are taken out with a pipette (made by drawing out a small glass tube) and evaporated to dryness in a small test-tube or on a watch glass. The dry residue is taken up in two or three drops of 6N·HCl and a drop or two of alpha-nitrosobeta-naphthol solution is added. A flocculent red precipitate slowly appears if cobalt is present. The reagent should be made up fresh at least once a month by dissolving one-half gram of the salt in 15 cc. of glacial acetic acid, diluting with an equal amount of water and filtering.

Copper—63.6

1. *Flame Color.*—Copper oxide and some copper minerals, if introduced in a finely divided form into the clear flame, give an **emerald-green** color. Fragments of copper minerals will often give this color B.B. The powder or a fragment of a copper mineral, if ignited on charcoal B.B. (in the O.F. if it is a sulphide or arsenide, etc.), moistened with hydrochloric acid and again ignited, gives the brilliant **azure-blue** flame color of **copper chloride.** The blue is usually tinged with green, owing to the partial decomposition of the chloride to the oxide. This is a very characteristic test.

2. *Reduction to Metallic Copper on Charcoal.*—Copper is easily reduced from its oxides, or from minerals containing the oxides, when heated strongly on charcoal, with a flux in the R.F. With a little patience and continued heating, the reduced copper may be collected into a globule. Since copper is rather hard to fuse B.B., it is best to take a rather small quantity of mineral and to use about three volumes of flux, which may be sodium carbonate, although, where metals not easily reduced, like iron, are present, a mixture of equal parts sodium carbonate and borax will be found to yield better results. *Minerals containing volatile elements (S, As, Sb) should be carefully roasted* (see p. 13) *before fluxing and reducing.* The globules, which are covered with a black coating of oxide, may be easily recognized by their toughness, malleability, and their reddish color, when cut or hammered.

3. *Color of Solutions.*—Acid solutions of copper salts are either green or blue-green. If an excess of ammonia is added to these a **deep blue** solution is obtained. Care should be taken in not confusing green solutions of nickel salts with those of copper, or the blue produced by ammonia in copper solutions with a very similar, but fainter, blue produced in the same way in nickel solutions.

4. *Bead Tests.*—In the O.F. copper oxide colors the borax and salt of phosphorus beads green when hot, and **blue** or **bluish-green** when cold, due to the presence of dissolved cupric oxide, CuO. In the R.F., if only a little oxide is present, the colors are paler, but if considerable is there, there is a separation of cuprous oxide, Cu_2O, or even of metallic copper, which makes the bead appear an **opaque red** in reflected light.

Perhaps the best way to effect the reduction of copper in the bead, especially if there is only a little present, is to remove it from the wire after it has been heated in the O.F., and heat it in the R.F. on charcoal, with a small granule of tin. The tin takes oxygen away from the CuO, reducing it to Cu_2O, or copper. Too long heating may cause the formation of a copper globule

Fluorine, F—19

1. *Test with Potassium Bisulphate. This test is limited to minerals, which contain considerable fluorine, and are decomposed by the bisulphate reagent.*—Mix the finely powdered mineral with three or four volumes of potassium bisulphate, and heat the mixture, gently at first, in a large closed tube (an open tube sealed off), or much better, a bulb tube. Hydrofluoric acid will be liberated, which reacts with the silica in the glass of the tube, etching this, and forming a **volatile** compound, **silicon fluoride,** SiF_4, which passes up the tube with the water formed by the reaction ($SiO_2+4HF=SiF_4+2H_2O$). In the cool part of the tube these products react according to the equation, $3SiF_4+2H_2O=2H_2SiF_6+SiO_2$, and deposit on the sides of the tube as a **white ring.** This white ring is the **most characteristic part of the**

reaction, although the etching on the tube in the immediate neighborhood of the fusion may usually be seen. The ring is **volatile** when heated, and may be made to pass up the tube. This is because the compounds H_2SiF_6 and SiO_2 when heated form SiF_4 and H_2O again. To **complete** the test, cut off the tube just below the ring, wash the inside of the tube carefully with water to remove the H_2SiF_6, which is soluble, and then dry the tube in the flame, when a **nonvolatile white ring of SiO_2 will remain.** Where very small amounts of substance are to be tested it is advisable to mix a little powdered silica or glass with the bisulphate, as this ensures the formation of the SiF_4 if fluorine is present. The above test is particularly serviceable where small precipitates of calcium fluoride, obtained as described under § 3, are to be tested.

2. *Test with Sodium Metaphosphate.*—This test can be applied to minerals which are not decomposed by the bisulphate of potash, provided not less than 5 per cent of fluorine is present. From four to six parts of sodium metaphosphate, $NaPO_3$, to one of the mineral should be used. Hydrofluoric acid is liberated, etches the glass, and deposits a ring of silica as described under § 1. The sodium metaphosphate may be made by fusing some salt of phosphorus in a platinum dish, or on a loop of platinum wire until the water and ammonia are expelled.

3. *Precipitation as Calcium Fluoride.*—This test is especially useful in detecting the presence of small quantities of fluorine in silicates. The mineral must be first decomposed with sodium carbonate, as described under silica (p. 58). The fusion is pulverized, boiled in a few cc. of water to soak out the sodium fluoride, which has been formed if fluorine is present, and filtered. The filtrate is acidified with hydrochloric acid, boiled to expel carbon dioxide, made strongly alkaline with ammonia, and a little calcium chloride added, to precipitate the fluorine as calcium fluoride. Other substances may be precipitated along with the calcium fluoride, so that it is necessary to filter off the precipitate, wash well with water, ignite the paper in a crucible, and test the residue according to § 1.

4. *Acid Water in the Closed Tube.*—Some minerals containing

fluorine and hydroxyl yield acid water (due to the presence of HF) in the closed tube (tested with litmus paper), and sometimes etch the glass. Unless, however, the etching is distinctly seen, the presence of fluorine must be proved by one of the other tests.

Germanium, Ge—72.5

This exceedingly rare element is only known to occur in the minerals argyrodite, canfieldite, and in small quantities in euxenite.

Sublimate on Charcoal.—When argyrodite is heated on charcoal B.B. germanium yields a white coating near the assay. On longer heating this moves further away, and assumes a lemon-yellow color mixed with a greenish to brownish shade; examined with a lens the coating appears glazed, and occasional transparent or white globules may be seen.

Gold, Au—197.2

Gold, when it is not present in the specimen in such form that it can be recognized by its physical properties, is usually tested for by assay methods. For these methods, as adapted for blowpipe tests, see under Silver; also Brush and Penfield's "Blowpipe Analysis," pp. 78–80; R. H. Richard's "Notes on Blowpipe Assaying," and Plattner's "Blowpipe Analysis," by Cornwall, eighth edition, p. 374.

Metallic gold is fusible B.B. on charcoal and does not yield a coating of oxide. It is insoluble in any single acid, but dissolves in aqua regia. Its yellow color and great malleability are striking physical characteristics.

Hydrogen, H—1

Hydrogen occurs in many minerals in combination with oxygen, and when such are heated, the hydrogen, united to the oxygen, is given off in the form of water. Testing for hydrogen amounts, therefore, to testing for water; see page 73.

Iodine, I—126.9

1. *Closed Tube Tests.*—Heated in the closed tube with potassium bisulphate, with or without manganese dioxide, iodides are decomposed, yielding a violet colored vapor.

When silver iodide, which is the only important iodine mineral, is heated in the closed tube with galena, PbS, a sublimate of lead iodide is obtained, orange-red when hot, lemon-yellow when cold.

Silver iodide is precipitated by silver nitrate, and differs from the bromide and chloride by not being readily soluble in ammonia.

Iridium (see under Platinum)

Iron, Fe—55.8

1. *Test with the Magnet.*—If placed in the field of a strong electro-magnet, with its poles close together so as to give a concentrated field, a great many minerals containing iron are attracted. **Magnetite** and **pyrrhotite** are the only common minerals strongly attracted by the ordinary magnet, and even pyrrhotite from some localities is but feebly acted on. Franklinite, a variety of magnetite, is somewhat attracted, and many minerals may be attracted **because they contain small grains of magnetite.** Many minerals containing iron become, however, **magnetic after heating B.B. in the R.F.** This applies especially to the sulphides, oxides, and carbonates, also to the silicates and phosphates, if the content of iron in them is large. The silicates, phosphates, etc., give a better reaction, however, if they are fused in the R.F. with about two volumes of sodium carbonate, the fusion crushed, and tested with a magnet.

Always wait until the fragment or powder which has been heated *is cold before testing with the magnet.* Even iron, when red hot, is not magnetic.

2. *Tests for Ferrous and Ferric Iron.*—Soluble iron minerals may be dissolved in a test-tube with hot hydrochloric or sulphuric acid without altering essentially the state of oxidation of the iron

from that existing in the original mineral. The resulting solution may then be tested for ferrous and ferric iron.

Ferrous Iron.—Ferrous iron gives a deep blue precipitate, exactly like Prussian blue in appearance, when *potassium ferricyanide* is added to a cold dilute solution of a ferrous salt. Potassium ferrocyanide produces a bluish-white precipitate in ferrous iron solutions, which, however, turns rapidly blue as it absorbs oxygen from the air.

Ferric Iron.—Potassium ferrocyanide when added to a solution of a ferric salt produces a deep blue precipitate of ferric-ferrocyanide, Prussian blue. Potassium ferrocyanide deepens the color of solutions of ferric salts, but produces no precipitate.

Ammonium Sulphocyanate.—Ammonium sulphocyanate produces a blood-red color in solutions of ferric salts, even in exceedingly dilute solutions.

Conversion of Ferrous into Ferric Iron, and vice versa.—By boiling a solution of a ferrous salt with a few drops of nitric acid the ferrous iron changes to the ferric state, with the formation of the ferric salt.

Ferric iron may be reduced to ferrous by boiling the hydrochloric acid solution with metallic tin or zinc ($2FeCl_3+Sn=2FeCl_2+SnCl_2$) until the yellow color of ferric chloride disappears.

3. *Precipitation with Ammonium Hydroxide.*—When ammonium hydroxide is added in excess to a solution of a ferric salt, a brownish-red precipitate of ferric hydroxide is thrown down. This is the most convenient way of removing iron from a solution. Ferrous iron should be converted into ferric iron, as directed above, before attempting to precipitate with ammonia, since ferrous iron is only partly precipitated and forms a dirty-green precipitate. Silica, if present, should be removed, see § 1, p. 57.

4. *Detection of Ferrous and Ferric Iron in Insoluble Minerals.*—Fuse thoroughly a small amount of the *finely* powdered mineral with three or four volumes of borax in a large-sized closed tube, in the Bunsen burner. Crack the tube about the fusion while still hot by touching it with a few drops of cold water. Break the end off and boil it for a minute in a test-tube with 3 cc.

of previously boiled hydrochloric acid, dilute with a little previously boiled water, divide quickly into two parts, and test for ferrous and ferric iron as directed under § 2 above.

5. *Bead Tests.*—The colors imparted by the oxides of iron to the fluxes vary considerably with the amount of material used, and are not very decisive. They are, however, frequently met with in making bead tests, and it is well to bear them in mind.

		Borax		Salt of Phosphorus	
		Little Oxide	Much Oxide	Little Oxide	Much Oxide
Oxidizing Flame	Hot	Yellow Amber	Brownish-Red	Yellow	Brownish-Red
	Cold	Colorless	Yellow	Colorless	Through Yellow to nearly colorless
Reducing Flame	Hot	Pale Green	Bottle Green	Pale Yellow	Brownish-Red
	Cold	Colorless	Pale Green	Through Pale Green to colorless	Through Yellowish-Green to colorless or Pale Violet

Lead, Pb—207.2

1. *Sublimate from Lead Minerals on Charcoal.*—Lead minerals when heated B.B. on charcoal yield a coating of lead oxide, or if sulphur is present and the mineral is heated rapidly, of some combination of lead oxide and sulphur dioxide. The lead oxide coat is rather readily volatile in both flames. It is orange-yellow when hot, fading to yellow when cold. On the outside the coating appears bluish-white. The coating obtained from lead sulphide when the latter is heated rapidly, is yellow only quite near

the assay, and is a dense white further away, bordered with blue. It is also quite volatile and resembles, except for the yellow color near the assay, the coating obtained from antimony, with which it should not be confused. If the sulphur is first carefully roasted off, the normal lead oxide coat is then obtained on heating in the R.F. Some minerals containing lead, antimony and sulphur, like jamesonite, give a very volatile coating, on charcoal B.B., yellowish or brownish yellow near the assay, white to bluish white further away. Careful roasting, using a small O.F., will give an antimony oxide sublimate first and the lead oxide coat may be obtained later. With such minerals the O.T. test should be used as a confirmatory test. To detect antimony and arsenic in the presence of lead the open-tube test may be used. See 4, page 24, and 3, page 25.

2. *Reduction of Lead Minerals to Metallic Lead on Charcoal.*—For this test mix 4 cmm. of the mineral to be tested with an equal volume of charcoal dust and three or four volumes of sodium carbonate, and fuse on charcoal B.B. in the R.F. Metallic lead, if present, will be reduced and may be collected into a globule. The globule is bright in the R.F., iridescent in the O.F., owing to a film of oxides, and quickly tarnishes in the air to a dull gray. It is soft and highly malleable. B.B. lead is somewhat volatile, and combines with oxygen from the air, depositing on the charcoal as a coating of lead oxide. By heating in the O.F. the lead globule may be entirely converted into lead oxide, which volatilizes and deposits on the coal.

The above test is very characteristic, but is sometimes rendered doubtful by the presence of other elements, especially bismuth. For the method of separating lead and bismuth in the wet way, see 3, p. 30. When antimony is present it should be removed as much as possible by roasting in a very small O.F. before reducing with sodium carbonate on charcoal.

3. *Iodine Tests, Distinction between Lead and Bismuth.*—If a coating of lead oxide be moistened with a few drops of hydriodic acid and heated in a small blowpipe flame, a *chrome-yellow* deposit of lead iodide is formed. When very thin this appears greenish-

yellow. This deposit is readily distinguished from bismuth iodide, which is red. The same coating can be made by heating the original mineral with a mixture of equal parts potassium iodide and sulphur, in an oxidizing flame, on charcoal or the plaster tablet.

4. *Precipitation of Lead as Chloride or Sulphate.*—Lead chloride or lead sulphate may be thrown down in the form of white precipitates, from not too concentrated solutions of lead minerals in nitric acid, by adding hydrochloric or sulphuric acid respectively. The chloride is quite soluble in hot dilute acids and hot water. It, therefore, will frequently not precipitate in hot solutions, but comes down on cooling as a crystalline precipitate. Solutions of lead minerals in hot dilute hydrochloric acid will deposit crystals of lead chloride on cooling. The sulphate precipitates as a finely divided white powder which is very insoluble. It may be filtered off and tested B.B. on charcoal.

5. *Flame Coloration.*—Lead minerals when heated in the R.F., either in the forceps (care should be taken not to alloy the forceps) or otherwise, impart a pale azure-blue color tinged with green to the flame.

Lithium, Li—6.9

Lithium minerals can usually be told by the brilliant crimson color imparted by lithium to the flame. The crimson of lithium is sometimes obscured by the presence of other substances, especially sodium. Where only a little sodium is present it may often be gotten rid of by first heating in the cooler part of the flame for a time until the sodium has burned off, and then, where it is hotter, when the lithium flame may be seen. When much of the interfering substance is present the spectroscope must be resorted to.

No lithium minerals give an alkaline reaction on moistened test paper after ignition, which will serve to distinguish them from strontium minerals.

Magnesium, Mg—24.3

1. There are no very satisfactory blowpipe tests for magnesium. It must therefore in general be tested for by the regular analytical methods. These involve the removal from the solution in which the magnesium is to be finally precipitated as ammonium magnesium phosphate, of all interfering elements, according to the methods prescribed in qualitative analysis. As a matter of fact in the ordinary run of mineral determinations, magnesium is met with in minerals where the interfering elements are rarely other than silicon, iron, aluminium, calcium, and very small amounts of manganese, and these can be removed very simply and quickly. Where a silicate is to be examined the method of procedure is described on page 58, § 4. In the case of minerals where silica is absent it is only necessary to carry out the procedure, beginning with the precipitation of iron, etc., with ammonium hydroxide. In any case, the final solution containing the magnesium should be cold and strongly alkaline with ammonia, and should also not be too dilute, that is, it should not exceed 15 cc. in volume where the original amount of substance was from 0.1 to 0.2 of a gram. To this solution an excess of soluble phosphate (usually hydrogen sodium phosphate, or microcosmic salt) is added. If precipitation does not result at once, the solution is allowed to stand for some time with occasional stirring.

2. Magnesium oxide, hydroxide or carbonate, if ignited B.B. after moistening with cobalt nitrate solution, assume a faint pink color. Slight impurities render this test uncertain.

Manganese, Mn—54.9

Manganese can be readily detected by the colors which it imparts to the sodium carbonate or borax beads.

1. *Sodium Carbonate Bead.*—Minerals, containing even a small percentage of oxide of manganese, if finely powdered and fused in a sodium carbonate bead in the O.F., form a compound, sodium manganate, Na_2MnO_4, which imparts a bluish-green

color to the bead when it is cold. This is a very delicate test and is not interfered with by other substances. Larger amounts of powdered mineral fused on a platinum foil with sodium carbonate and a little potassium nitrate (to supply oxygen) over the Bunsen flame may be used to detect amounts of manganese as small as a fraction of 1 per cent.

2. *Borax Bead.*—Small quantities of manganese oxide dissolve in the borax bead when heated in the O.F., coloring it a fine reddish violet. If the bead is then heated in a *strong, smoky* R.F. for some time, *entirely out of contact with the air*, the color may be wholly destroyed by a reduction of the higher oxide of manganese to MnO, which forms a colorless compound with borax. Too large amounts of manganese will give a black or nearly black bead, and care should be taken to avoid such an excess. This test is sometimes rendered unreliable by the presence of other oxides, such as iron, which impart a color to the bead, and where these are present, or suspected to be present, the sodium carbonate bead should be used.

Salt of Phosphorus Bead.—The colors imparted to the salt of phosporus bead are similar to those obtained with borax, but are less satisfactory.

Mercury, Hg—200.6

1. *Closed-tube Test.*—The only common mercury mineral is the sulphide, HgS. If this is heated alone in the closed tube it sublimes, and deposits on the cool part of the tube as a black sublimate. The only other permanently black sublimate obtained from minerals is that of arsenic, which is easily distinguished from the HgS.

Mercury compounds when fused with sodium carbonate in the closed tube are decomposed and metallic mercury is formed. This distills up the tube and collects on its walls as a gray sublimate composed of minute globules of mercury. These globules may be collected into larger ones by rubbing them with a wire or match end. About three volumes of *dry* sodium carbonate should be mixed with the mineral, and a layer of the same *dry* carbonate placed on top of the mixture in the tube, so as to catch and react with any of the mercury mineral, which might otherwise escape by volatilization. We may illustrate the reactions which take place in the closed tube with the mineral cinnabar, HgS, as follows: $HgS + Na_2CO_3 = \underline{Hg} + O + CO_2 + Na_2S$.

2. *Open-tube Test.*—The sulphide of mercury when heated *slowly* in the open tube yields a gray sublimate of metallic mercury. This may be collected into globules by rubbing with a match end or a platinum wire. Mercuric oxide, which is formed by the reaction, is broken down by the heat into oxygen and mercury. The latter condenses on the walls of the tube.

Molybdenum, Mo—96

1. *Tests for Molybdenum when in form of Sulphide. Coating on Charcoal.*—If the sulphide of molybdenum is heated for some time on charcoal in a strong oxidizing flame, a sublimate of molybdenum trioxide, MoO_3, is deposited on the coal a short distance from the assay. The sublimate, which is easily volatile, is pale yellow when hot, nearly white when cold, and is often distinctly crystalline. If the sublimate be heated for an instant in the reducing flame, it assumes a fine blue color due to a partial reduction of the MoO_3. Nearer the assay, a thin, tarnished, copper-colored coating of MoO_2 can be seen.

Molybdenite, MoS_2, yields a yellowish sublimate of MoO_3 in the open tube if heated for some time at a high temperature. The sublimate often takes the form of a mass of slender crystals.

2. *Test for Molybdenum in Molybdates.* Boil a small quantity of the powdered molybdate with about 3 cc. of hydrochloric acid in a test-tube until the acid is nearly all evaporated, that is, almost to dryness; cool, add about 5 cc. of water and a piece of tin. On warming, a deep blue color forms. The hydrochloric acid decomposes the molybdate, leaving on evaporation molybdic acid, which is reduced by the tin to a blue compound.

3. *Bead Test with Salt of Phosphorus.*—With medium quan-

tities, if heated in the O.F., the bead is yellowish green when hot, almost colorless when cold. In the R.F. it is a dirty green when hot, turning to a fine green on cooling. The colors obtained with the borax bead are not satisfactory.

4. *Flame Test.*—Some molybdenum minerals may yield on heating a pale yellowish-green flame coloration. This is intensified by moistening with sulphuric acid, but is not a very satisfactory test.

Nickel, Ni—58.7

1. *Bead Tests.*—Of the bead tests for nickel, those with borax are the most reliable.

		BORAX	SALT OF PHOSPHORUS	
			WITH LITTLE	WITH MUCH
Oxidizing Flame	HOT	Violet	Reddish	Brownish Red
	COLD	Reddish Brown	Pale Yellow	Reddish Yellow
Reducing Flame	HOT	Becomes opaque from the separation of metallic nickel.	Remains unchanged. Heated with a grain of tin the bead becomes colorless.	
	COLD			

2. *Colored Solutions.*—Nickel colors nitric acid solutions apple green, and if such solutions are made alkaline with ammonia, a blue color is obtained which resembles the blue obtained from copper solutions in the same manner, but is not so intense. The flame color, or other tests, will serve to distinguish copper from nickel minerals.

3. *Test for Nickel in Presence of Cobalt.*—A small amount of cobalt will obscure the bead test for nickel and confuse the coloration in acid solution. When, therefore, it is desired to test for nickel in the presence of cobalt, the following method may be used:

The powdered mineral is dissolved by warming in a few cc. of conc. HNO_3. After cooling and dilution, any residue is filtered off, and the solution is made alkaline with ammonia. To this solution, when hot, a solution of dimethylglyoxime is added. This precipitates the nickel in the form of a bright scarlet precipitate. If iron is present, tartaric acid must be added to the solution before the ammonia, in order to prevent the precipitation of the iron with the nickel.

Niobium, Nb (Columbium, Cb)—93.1

1. *Reduction Test.*—In order to get niobium minerals, which are as a rule very insoluble in acids, into solution for this test, it is best to decompose them by fusion on a large loop of platinum wire with about five volumes of borax. After two or three such fusions have been made, crush the resulting beads to a fine powder and boil with a few cc. of hydrochloric acid. If this solution, which will usually be clear, is now boiled with a piece of tin, a persistant blue color, due to the reduction of the niobium by the tin, will be obtained. If considerable titanium is present it will also be reduced, but will show a violet color (see titanium, p. 69) before the blue, due to niobium, appears. To distinguish tungstates, which also give a blue color when treated as above, see under tungsten, p. 71.

Nitrogen, N—14

The few natural nitrates of the heavy metals are readily decomposed with the evolution of nitrogen dioxide gas, NO_2, by heating alone in the closed tube. This gas is easily recognized by its odor and brown color.

NO_2 is given off by nitrates of the lighter elements when they are heated in the closed tube with potassium bisulphate.

Oxygen, O—16

1. Oxygen is rarely tested for directly in minerals, but its presence or absence is inferred from the character of the other component elements and their behavior. A few higher oxides, notably those of manganese, give off oxygen when heated in the *closed tube.* In making this test the substance is placed in a closed tube in which, a short way above the assay, is also placed a splinter of charcoal. The splinter is heated to redness at the same time, or just before, the substance is ignited. The oxygen, which will be given off if a higher oxide is present, will cause the splinter to burn. To illustrate, the dioxide of manganese, pyrolusite, reacts as follows: $3MnO_2 = Mn_3O_4 + 2O$.

2. When some of the higher oxides are dissolved in hydrochloric acid, an amount of chlorine is liberated equivalent to the oxygen which is in excess over that demanded by the lower valence of the metal. The higher oxides of manganese, which are common minerals, are often tested this way. To illustrate again with one of them, pyrolusite: $MnO_2 + 4HCl = MnCl_2 + 2H_2O + 2Cl$. The chlorine is easily recognized by its pungent odor and its bleaching action on moist litmus paper.

Palladium (see under Platinum)

Phosphorus, P—31

1. *Flame Test.*—Most phosphates when moistened with sulphuric acid and ignited B.B. color the flame a pale bluish-green. Many yield the coloration without the use of the acid.

2. *Ammonium Molybdate Test.*—A yellow precipitate of ammonium phosphomolybdate is thrown down, when a nitric acid solution of a phosphate is *added to* an ammonium molybdate solution. The solutions should be cold, and that of the phosphate added a few drops at a time to the molybdate solution. Phosphates which are insoluble in nitric acid may be first fused with sodium carbonate and then dissolved. If it is found neces-

sary to use some other acid than nitric, the acid must be nearly neutralized with ammonia before the precipitation is made. Molybdenum forms a similar compound with arsenic, which comes down, however, only from a hot solution, hence the advisability of having a cold solution in testing for a phosphate.

3. *Test with Metallic Magnesium.*—This test depends upon the formation of phosphine, PH_3, which is recognized by its disagreeable odor. It is best to make the test as follows: Roll closely 2 to 3 cm. of magnesium ribbon and place it in the bottom of a closed tube. Surround the ribbon with the finely powdered mineral, getting as close a contact as possible, and heat intensely B.B. (*The tube should be pointed so that if an explosion occurs the contents will not be shot out of the end toward any one.*) Crack the tube with water while still hot, moisten the contents with a few drops of water, and note the odor.

Platinum, Pt—195.2

Platinum is recognized by its silver-gray color, malleability, high specific gravity, infusibility, and insolubility in any single acid. It dissolves in aqua regia, and if its solution is evaporated nearly to dryness, taken up in hydrochloric acid, again evaporated, taken up in a little water, and a concentrated solution of ammonium chloride added, a yellow precipitate of ammonium platinic chloride, $(NH_4)_2PtCl_6$, will form.

The other members of the platinum group, Iridium, Palladium, Osmium, etc., demand highly special methods for their identification. For these methods see paper by A. A. Noyes, "Technology Quarterly," Vol. XVI, No. 2, June, 1903, or "Qualitative Analysis," Treadwell-Hall, Vol. I, 1916.

Potassium, K—39.1

1. (*a*) *Flame Test.*—Volatile potassium compounds color the flame a pale violet. This color is easily obscured by other substances, especially by the intense yellow flame of sodium. It is therefore usually necessary to use a rather thick blue glass to absorb the interfering color. Through this the potassium flame appears purplish red or violet, depending on the shade and thickness of the glass.

(*b*) *Silicates and other minerals* containing potassium, which do not color the flame, may be mixed with an equal volume of *powdered gypsum*, $CaSO_4 \cdot 2H_2O$, and introduced into the Bunsen flame on a fine platinum wire. Potassium sulphate is formed by the reaction between the gypsum and the mineral, and gives the potassium flame color if viewed through the blue glass.

2. *Precipitation as Potassium Platinic Chloride.*—Hydrochlorplatinic acid produces in concentrated aqueous, or slightly acid solutions of potassium salts, a yellow, crystalline precipitate of potassium platinic chloride, K_2PtCl_6. The addition of alcohol (95%) renders the precipitation complete. Ammonium salts must be absent, as they form a similar compound $(NH_4)_2PtCl_6$, which comes down as a yellow precipitate. Ammonium salts may be removed by evaporating the chloride solution to dryness and igniting the residue gently until all fuming, due to ammonium salts, stops.

Insoluble silicates must be fused with four volumes of sodium carbonate, the fused mass dissolved in hydrochloric acid, evaporated to dryness, taken up in a few cc. of water, boiled, an equal volume of alcohol added, the solution filtered, and the potassium tested for by the addition of a few drops of H_2PtCl_6.

3. *Precipitation in Potassium Perchlorate.*—The dried chlorides are obtained as directed under § 2, above. These are just dissolved in two or three drops of water, filtered if necessary, brought just to dryness again, and 1 or 2 cc. of perchloric acid solution is added together with 10–15 cc. of 80 per cent alcohol. A white crystalline ppt. indicates potassium.

4. *Alkaline Reaction.*—With the exception of the silicates, phosphates, and the salts of a few rarer acids, potassium compounds give an alkaline reaction on moistened test paper after ignition B.B.

Rare Earths

The so-called rare earth elements properly include two groups, the *Cerium earths*, cerium, lanthanum, and didymium, and the *Yttrium earths*, yttrium, erbium, etc. With these are often included thorium and zirconium. They often occur associated in quite a number of rare minerals, which also frequently contain other elements, such as uranium, titanium, niobium, and tantalum. They are detected by wet methods, which are in general quite complicated. Below are given directions which will enable one to separate and detect the earths, including thorium and zirconium. For more complete tests, reference must be made to analytical treatises on the analysis of the rare earths.

Wet Tests for Rare Earths.—If insoluble * in acids the substance is decomposed by fusion with sodium carbonate, or if this flux does not readily effect decomposition, borax may be used (certain niobates, etc.), and silica, if present, is removed, as directed on page 58. A small excess of ammonium hydroxide is now added to the hot solution, and any precipitate formed is quickly filtered and washed with hot water. This precipitate will contain the earths, and may also contain a variety of other elements which are thrown down with ammonia, but the alkali earths will pass into the filtrate. The precipitate is next dissolved in dilute nitric acid, and the solution evaporated to dryness (the last part of the evaporation should be carried out on a water bath to avoid overheating the residue).

The residue is taken up in a little warm water, and to the boiling solution, a hot solution of strong oxalic acid is added in excess. The solution is allowed to stand for some hours in a warm place, then filtered and washed. The precipitate contains the earths and thorium as oxalates; the filtrate contains any zirconium and uranium. These may be tested for as directed on pp. 75, 71.

The precipitated oxalates are next ignited in a crucible for

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* Several rare earth minerals, which are not attacked by HCl or HNO_3, are easily decomposed by strong H_2SO_4. After *cooling* and dilution with water, the solution, filtered if necessary, is treated with ammonia, etc., as directed.

some time over a strong Bunsen flame to decompose them to oxides. These are then dissolved in as little nitric acid as possible and the solution evaporated *just* to dryness. To the dry nitrates, a cold saturated solution of potassium sulphate is added, also a few crystals of the salt to insure saturation. Allow to stand twelve hours or more. The cerium earths and thorium, if present, will form insoluble, double sulphates. These may be filtered off, washed with the same saturated sulphate solution, and dissolved in water. If the precipitate is large it is advisable to repeat the precipitation as double sulphates after having first dissolved the original precipitate in water, reprecipitated the earths again as hydroxides with potassium hydroxide, filtered, washed, redissolved in nitric acid, and evaporated just to dryness as before. In any case, the cerium earths and the thorium are obtained in the form of dry nitrates as just described. A large excess of hot ammonium oxalate solution is poured over them and the whole is allowed to stand for some hours. The cerium earths are precipitated as oxalates, while the thorium is held in solution. The thorium may be thrown out by slightly acidifying the filtrate from the earths with nitric acid, and boiling. The thorium may be further tested by igniting the precipitated oxalate (the oxide thus obtained should be white), dissolving in HNO_3, evaporating to dryness, and taking up in a hot ammonium oxalate solution, when it should entirely dissolve. The presence of cerium is indicated if the ignited oxalates yield a salmon-brown oxide on ignition, and it may be further tested for by a salt of phosphorus bead test. In the O.F. the bead is yellow to orange while hot, fading to colorless when cold. If the nitrate solution has a distinct pink color, didymium is present.

The yttrium earths, if present, may be thrown out from the sulphate solution by adding potassium hydroxide. The precipitated hydroxides, after washing and ignition, may be dissolved in nitric acid, and after removing the acid by evaporation, the earths are precipitated as oxalates with ammonium oxalate.

For further details relating to the detection of these elements see " Qualitative Analysis," by Treadwell-Hall, Vol. I, 1916.

Selenium, Se—79.2

1. *Before the B.B. on Charcoal and in the Forceps.*—The rare element selenium and its compounds when heated B.B. in the R.F., in the forceps or on charcoal, *color* the *flame* an *intense azure-blue*, and give off a peculiar, disagreeable odor which may perhaps be described as resembling that of decomposed horse-radish. On charcoal, if much selenium is present, a silvery coating of selenium oxide, SeO_2, is obtained, generally bordered on the outside by a reddish or brownish coat of finely divided selenium. If this coat, which is volatile, is touched with the R.F. an azure-blue flame color is obtained.

2. *Open Tube Reactions.*—SeO_2 is formed as a sublimate in the open tube. It fuses to colorless globules, sometimes reddened by the presence of metallic selenium. These crystallize and whiten on cooling. If the SeO_2 is volatilized from the end of the tube and the end held in the Bunsen flame, the latter will be colored azure-blue.

3. *Closed Tube Reactions.*—Selenium is set free from some of its compounds when they are heated in the C.T. and deposits as fused reddish or brownish globules on the walls. Some selenium oxide is generally formed and deposits with the selenium, but a little further up the tube.

Silicon, Si—28.3

Silicon occurs in nature, either in the form of the oxide, SiO_2, or in combination with a considerable variety of bases forming the silicates, salts of the various silicic acids. The silicates fall rather sharply into three groups as regards their behavior toward the common acids, HCl, HNO_3. These are:

1. *Silicates which Yield a Jelly upon Evaporation with Acids.*—If the fine powder of a silicate of this group be boiled with dilute nitric or hydrochloric acid and evaporated, a point is finally reached where the solution thickens, owing to the separation of silicic acid as a gelatinous mass. On evaporating this to dryness,

the silicic acid is dehydrated and a residue of insoluble silica, SiO_2, is left. The silica, after warming with dilute HCl, may be filtered off and thus completely removed from the solution, which may then be tested with (see § 4) appropriate reagents for the other elements present. The silica may be examined as directed under § 5 or § 6.

2. *Silicates which are Decomposed by Boiling with Dilute Acids, with the Separation of Non-gelatinous, Powdery or Flakey Silica.*—Silicates of this group are **often mistaken for insoluble minerals,** that is to say, the silica suspended in the solution is mistaken for undissolved mineral. In order to be sure that decomposition has occurred, it is best to filter off the silica, and either evaporate a drop or two of the filtrate on a piece of glass or platinum to see if a residue of dissolved bases remains, or test the filtrate with reagents as directed under § 4, to see if it contains any bases in solution.

3. *Silicates which are Insoluble in Acids.*—Most insoluble silicates may be completely decomposed by fusion with four to five parts of sodium carbonate. In the few cases where this is not effective, borax may be used. The fusion may be made on charcoal or on a large loop of platinum wire, or in a platinum capsule. From 0.1 to 0.2 of a gram of *very finely powdered* mineral should be used in making this fusion. After the fusion is made the pulverized mass is dissolved in dilute nitric acid (5 cc. of 6N. HNO_3) in a test-tube, and evaporated to dryness.

Toward the end of the evaporation gelatinous silica will usually separate from the solution. The dry residue in the tube should now be moistened with a few drops of hydrochloric acid and boiled with 5 or 10 cc. of water. This treatment leaves the silica as an insoluble powder in the solution, while the bases are dissolved. The silica may be filtered off and tested according to § 5 or § 6. The filtrate may, if desired, be examined for bases as described under § 4.

4. *Special Method of Procedure for Detecting the Common Bases in Silicates.*—As the great majority of the silicates met with in practice, contain as bases one or more of the common

elements only, viz., sodium, potassium, calcium, magnesium, iron, and aluminium, very simple analytical methods may be used in determining their composition. The following directions, if followed closely, will be found rapid and convenient. With care the whole operation can be carried out in test-tubes, although a small casserole is convenient for the evaporation.

To the filtrate from the silica (§ 3, above) separation containing the bases in solution, add ammonium hydroxide in slight excess, when the iron and aluminium will be precipitated, if present, as hydroxides. If the precipitate is light colored, iron is absent, or present in small amount. The precipitate is now filtered, washed with hot water, transferred from the filter to a test-tube, about 5 cc. of water and a small piece of potassium hydroxide are added, and the solution boiled. The aluminium hydroxide goes into solution, leaving the ferric hydroxide undissolved. If the latter is filtered off, the aluminium in the filtrate may be precipitated with ammonia, after being distinctly acidified with hydrochloric acid. This precipitate may be filtered off and tested according to 1, p. 22.

The filtrate from the iron and aluminium precipitation is now heated to boiling and a hot solution of ammonium oxalate added slowly. Calcium, if present, will be precipitated, and after boiling a minute, is filtered. The calcium oxalate may run through the filter at first, but by passing the solution through once or twice more, this may be stopped. The precipitate may be tested according to 1 or 3, pp. 32–33.

The filtrate from the calcium precipitation, which should smell distinctly of ammonia, is cooled, and an excess of sodium hydrogen phosphate is added. Magnesium will be precipitated, if present, although it may not come down at once, so that it is best to allow the test-tube to stand a while after adding the phosphate solution.

For the detection of sodium and potassium, see p. 63 and pp. 53–54.

5. *Test in the Salt of Phosphorus Bead.*—Oxide of silicon dissolves very slowly in the salt of phosphorus bead, so that if a

silicate is fused in such a bead the bases go into solution, leaving behind a residue of silica. This is not, however, a very satisfactory test, as there are a number of minerals containing no silica which dissolve slowly in the salt of phosphorus bead.

6. *Test for the Oxide of Silicon.*—Oxide of silicon, if mixed with an equal volume of sodium carbonate and fused B.B. yields a clear, but not usually colorless, glass of sodium silicate. A clear glass is not obtained with silicates, with one or two exceptions. A small quantity, 2 to 4 cmm., is about the right amount to take. The test is especially adapted for testing the natural oxides of silicon, quartz, etc., and also for testing silica separated from solutions of silicates as described above.

Silver, Ag—107.9

1. *Reduction on Charcoal.*—Pure silver minerals can be easily reduced with a flux on charcoal B.B. to metallic silver, which fuses readily and can be collected into a globule. It may be recognized by its bright, silver-white surface and its malleability. The globule may be further tested by dissolving in dilute nitric acid and precipitating the silver as silver chloride, with HCl or a soluble chloride.

About three volumes of flux are recommended for the reduction of silver. The flux may be either sodium carbonate or a mixture of sodium carbonate with borax. A little powdered charcoal mixed with the assay facilitates the reduction. Where volatile metals are present, such as sulphur, arsenic, or antimony, the mineral must be carefully roasted in the O.F. before fluxing and reducing. Although silver itself gives no coating on charcoal, when it is associated with lead and antimony the coatings obtained from these elements may show a purplish color, which is said to be characteristic.

When small amounts of other reducible metals are alloyed with the silver globule, they may often be removed by heating the globule on a clean charcoal surface, in a borax bead, in the O.F., whereby the impurities are oxidized and the oxides formed dissolved in the borax. With larger amounts of reducible metals, assay methods must be resorted to, to obtain the silver in a pure form. For a complete and elaborate description of assay methods adapted for the blowpipe, and the apparatus used in carrying them out, the student is referred to R. H. Richard's "Blowpipe Silver Assay Notes," and Plattner's "Blowpipe Analysis," translated by Cornwall, eighth edition. With a little practice, however, entirely satisfactory qualitative and approximate quantitative results may be obtained in the manner described beyond. Very small quantities of silver may be detected in this way.

2. *Cupellation Method of Detecting Silver in Minerals and Ores.*—Mix about 0.2 gram of ore with an equal volume each of borax glass and test lead (pure lead), and transfer to a deep, funnel-shaped cavity in a nearly square piece of compact charcoal. Fuse the assay, heating gently at first to prevent mechanical loss, in the *smoky* reducing flame until the lead is all collected into a single globule. This is accomplished by manipulating the assay, always completely covered with the R.F., so that the lead globule, or button, passes through every portion of the melted assay. For this manipulation the charcoal is conveniently supported on the point of a jackknife or a forked piece of wire stuck into the under side of the coal. The coal can thus be easily turned to present all sides to the flame at will. When a single large globule is formed, the flame is changed to the clear O.F., which is manipulated much as the R.F. was before, and the globule is made to move through the melted assay. Lead oxide is formed, and passes into the slag, carrying with it the oxides of other metals, except silver, which were reduced in the lead globule. The lead oxide formed, not only acts as a flux for removing impurities, but by its formation reduces the size of the lead button. This oxidation should be continued until the globule is perhaps 2 to 3 mm. in diameter. The globule should now have lost its spherical shape, and on cooling should have, unless impurities are still present, a lead-white color, tinted slightly yellow by a thin coating of lead oxide. When copper is present, or if antimony or arsenic were present in the original substance and have

not been entirely volatilized, the button appears black. Where this is the case, a longer heating in the O.F., with the addition of a little test lead, is necessary to remove the impurities. The button is now removed from the slag and freed from adhering particles by hammering into a cubical form. A cupel of bone-ash is now made by pressing some fine bone-ash firmly into a large (say 1½ cm. in diameter and 5 mm. deep) shallow cavity on another square piece of charcoal, with the rounded end of an agate or steel pestle. The surface of the ash should be smooth, free from stray particles of ash or dirt, and must be thoroughly dried by intense ignition B.B. The button is now placed carefully on the cupel, and fused, first in a small R.F., then, far out in the O.F. The lead oxide formed is absorbed by the ash and takes away with it the last traces of impurities. The globule should be constantly moved about the surface of the cupel and the oxidation continued until all the lead is removed. This point may be told by the sudden disappearance (" blick ") of the brilliant play of colors on the surface of the globule. The silver bead is now spherical and should be of a perfectly silvery-white color. The bead should not adhere tightly to the cupel, but in case it does, it is a sign that it is not yet entirely free from lead. It may then be fused in the O.F., alone on a clean surface of the charcoal, or with borax, which may easily be dissolved away from the silver in hot water and hydrochloric acid. If the button of lead is so large that the amount of oxide formed is too much for one cupel to absorb, two cupels may be used in succession.

For quantitative determinations, weighed quantities of ore are taken, 0.2 to 0.3 gram being a suitable quantity. The final button of silver is then weighed accurately, or its weight is estimated, after measuring with a scale or microscope, the diameter of the button, which is approximately spherical.

Gold, if present in the ore, goes with the silver. It may be separated by boiling the globule with concentrated nitric acid, which dissolves out the silver. The gold may then be collected on a small paper filter. The filter, carefully folded into a little lump, is gently burned on a smooth surface of charcoal, the resulting ash and gold powder mixed with a bit of borax-glass and fused B.B., so as to bring the gold into a globule. The borax may be dissolved away and the gold weighed, if there is a weighable amount. Where the button of silver and gold is more than one-quarter gold, the silver cannot be all dissolved out by nitric acid. hence, in cases where the presence of considerable gold is suspected, a piece of pure silver (weighed if desired) somewhat larger than the button should be fused with it, after which the treatment with nitric acid may be carried out.

3. *Precipitation as Silver Chloride.*—Silver is precipitated when hydrochloric acid or a soluble chloride is added to a nitric acid solution of the metal. If the amount of precipitate is small, it appears as a white turbidity in the solution, if large, it is thick and curdy. On exposure to the light it turns purple. Silver chloride is soluble in an excess of ammonia.

Metallic globules, obtained from fusions on charcoal, are conveniently tested for silver by dissolving them in dilute nitric acid and adding a few drops of hydrochloric acid.

Sodium, Na—23

1. *Flame Test.*—The intense yellow flame color which sodium compounds impart to the flame is an exceedingly delicate test for sodium and is the one usually used for its identification. The sodium flame is entirely absorbed by blue glass, and in the spectroscope gives a single broad yellow band. The flame test is so delicate that it may be obtained from fragments of minerals containing no sodium, but which have been handled and so acquired a little sodium on the surface from the fingers. Unless, therefore, a persistent coloration is obtained it should not be taken as evidence of the presence of sodium.

2. *Alkaline Reaction.*—Sodium minerals, with the exception of the silicates, phosphates, borates, and salts of some rare acids, if ignited B.B., give an alkaline reaction on moistened turmeric or litmus paper.

Strontium, Sr—87.6

1. *Flame Test.*—Strontium compounds impart a brilliant crimson color to the flame. The flame test is most satisfactory when made by introducing a little of the fine powder, moistened with HCl, on a platinum wire into the edge of the Bunsen flame. Care should be taken not to confuse the red of strontium with the crimson of lithium, or the yellowish-red of calcium, when hydrochloric acid is used.

2. *Alkaline Reaction.*—In common with the other alkaline earth metals and the alkalies, strontium compounds (except silicates and phosphates) give an alkaline reaction on moistened test paper after intense ignition B.B. (compare reaction of lithium minerals (p. 46) which give no alkaline reaction).

3. *Precipitation as Sulphate.*—When sulphuric acid is added to a solution containing strontium a heavy white precipitate of strontium sulphate is formed. This precipitate, although somewhat soluble in hot water and hydrochloric acid, is much less so than the calcium sulphate, and this fact serves to distinguish it from the latter. If the solution to be tested is concentrated to a small volume (2 or 3 cc.), divided into two parts, and one of them diluted to 15 cc. with water, it will be found that sulphuric acid produces a precipitate in both, if strontium is present, although it will come down somewhat slowly in the dilute solution. (Compare Calcium, p. 33.) Some of the precipitated sulphate may be collected on a filter and introduced into the flame on a platinum wire to test it for the crimson flame color.

Sulphur, S—32

The method to be used in testing for sulphur depends upon whether it is in the form of a **sulphate** or a **sulphide,** that is, combined with oxygen or not.

A. TESTS FOR SULPHUR IN SULPHIDES

1. *Heating on Charcoal; Odor of Sulphur Dioxide.*—If a fragment of a sulphide is heated in the forceps or on charcoal B.B.,

the sulphur is volatilized and burns with the oxygen of the air, forming sulphur dioxide, SO_2, which is recognized by its extremely sharp, pungent odor. This test is even more effective if the powdered mineral is spread out thinly on the charcoal and roasted in the O.F. In the case of a few sulphides which contain a relatively small amount of sulphur, such as Cu_2S, or those like ZnS, which oxidize slowly, also sulphides which contain arsenic, the odor of SO_2 may not be easily detected. Hence tests § 2 or § 4 are in general the more reliable. Sulphur itself, and a few sulphides, burn with a pale blue flame.

2. *Heating in the Open Tube.*—If a little of a powdered sulphide is heated in the open tube, as directed on page 18, sulphur dioxide is formed and may be detected by its odor at the upper end of the tube. A piece of moistened litmus paper will turn red if held in the escaping fumes, and eventually will become bleached if much SO_2 is present. The open tube test for sulphur is very delicate, and is perhaps the most satisfactory "sulphide" test, so far as minerals are concerned. The formation of sublimates in the tube does not interfere with the test. A little sulphur trioxide is often formed by secondary reactions in the tube, and appears as a white smoke.

3. *Heating in the Closed Tube.*—Some sulphides decompose when heated in the closed tube, and give off a part of their sulphur, which volatilizes and deposits as a sublimate on the walls of the tube. It is dark red when hot, fading out gradually to a light yellow when cold. If the tube is broken off below the sublimate, and heated in the Bunsen flame, the odor of SO_2 may be obtained.

4. *Silver Coin Test.*—A very satisfactory test for sulphur may be made by heating a small quantity of the powdered mineral with about three volumes of sodium carbonate in a closed glass tube, until the mixture is fused, after which the tube is broken, the fusion placed on a clean silver coin, and moistened with water. If sulphur is present, a black stain will be formed on the silver. The sodium carbonate reacts with the sulphide forming sodium sulphide thus, $MS+Na_2CO_3=MCO_3+Na_2S$. The Na_2S, when placed on the coin, reacts with the water and with oxygen

from the air; $2Ag+Na_2S+H_2O+O=Ag_2S+2NaOH$. The fusion may be made on a clean piece of charcoal, but if the gas flame is used, a slight reaction is often obtained from sulphur which may be present in the gas.

5. *Oxidation with Nitric Acid.*—When a sulphide is boiled in concentrated nitric acid it undergoes more or less complete solution accompanied by oxidation. A portion of the nitric acid suffers decomposition in such a manner that it yields water, oxides of nitrogen, and oxygen, which latter oxidizes part, or all, of the sulphur to sulphuric anhydride, SO_3. The latter, of course, forms sulphuric acid with water, and may be tested for according to B, § 1. Usually more or less sulphur is set free during the early part of the reaction, which does not oxidize readily in that condition and so remains in suspension. This is especially true of those sulphides which dissolve readily in hydrochloric acid with the evolution of hydrogen sulphide (see § 6), and may be explained by assuming that some hydrogen sulphide is set free and at once oxidized by the action of the nitric acid, forming water and sulphur ($H_2S+O=H_2O+S$). During the action of nitric acid on a sulphide, red vapors of NO_2, nitrogen dioxide gas, are given off.

6. *Solution in Hydrochloric Acid; Evolution of Hydrogen Sulphide.*—Most natural sulphides are either insoluble, or difficultly soluble in hydrochloric acid. A few, however, dissolve with the evolution of hydrogen sulphide gas, which may be recognized by a disagreeable and highly characteristic odor resembling that of bad eggs.

B. DETECTION OF SULPHUR IN SULPHATES

1. *Precipitation with Barium Chloride.*—Barium chloride, when added to a dilute acid solution (hydrochloric or nitric) containing a sulphate, produces a dense white, highly insoluble precipitate of barium sulphate, $BaSO_4$. If the mineral is insoluble, it may be tested according to § 2, or it may be fused with five volumes of sodium carbonate, the sodium sulphate thus formed

soaked out by digesting in water, freed from the insoluble carbonate by filtration, acidified with hydrochloric acid, filtered again if necessary, and barium chloride added.

2. *Reduction to a Sulphide and Test on Silver Coin.*—Mix a little of the finely powdered mineral with four volumes of sodium carbonate (best dry) and one of charcoal dust, and fuse in a closed tube. Sodium sulphate is formed during the fusion and is reduced by the charcoal present to sodium sulphide, thus: $MSO_4 + Na_2CO_3 + 2C = Na_2S + MCO_3 + 2CO_2$. If the tube is now broken and the contents placed on a silver coin with water, a black stain of silver sulphide will be formed, the same as described under A, § 4.

2. *Decomposition in the Closed Tube.*—Some sulphates, viz., those with weak bases, such as iron, aluminium, etc., break down, giving off SO_3 when heated intensely in the closed tube, and when water of crystallization is present, as is usually the case, they yield acid water in the tube.

Tantalum, Ta—181.5

This metal usually occurs associated with niobium, chiefly in the mineral columbite, and in a few others. It also forms nearly a pure tantalate with Iron and Manganese.

To detect tantalum in the presence of niobium proceed as follows:

Fuse thoroughly the finely powdered mineral with five or six volumes of potassium bisulphate. Digest the powdered fusion with an excess of dilute sulphuric, finally boiling. Filter off the white oxides of tantalum and niobium, which will remain behind if these elements are present, and dissolve them in strong hydrofluoric acid in a platinum crucible or dish. To the concentrated solution thus obtained, a concentrated solution of potassium fluoride is added. This will form needle-like crystals of K_2TaF_7 and flat plates of K_2NbF_7 if these elements are present. The former is much less soluble in water (220 parts water dissolve 1 part of salt) than the latter. On boiling the water solution of the tantalum salt a difficultly soluble, white oxychloride of tantalum, precipitates out. This is a very delicate test for tantalum.

Tellurium, Te—127.5

1. *Sulphuric Acid Test.*—In the absence of manganese compounds, a delicate test for tellurium and tellurides may be made by warming a little finely powdered mineral in a test-tube with a few cc. of concentrated sulphuric acid, when, if tellurium is present, the solution will assume a characteristic reddish-violet color. If the solution is cooled and diluted, the color disappears, and a grayish-black precipitate of tellurium is thrown down.

2. *Fusion in Closed Tube with Sodium Carbonate and Carbon.*—Tellurium or tellurides, if powdered, and mixed with about three volumes of sodium carbonate and some charcoal dust, and fused in a large closed tube, will yield a reddish-violet colored solution, if, after cooling, water is introduced into the tube. If this solution is poured out and exposed to the action of the air, a gray precipitate of tellurium is formed.

3. *Test with KOH and Aluminium.*—The powdered mineral is gently warmed with a few cc. of a concentrated solution of KOH and some finely granulated metallic aluminium in a test tube. A deep purple coloration appears in the solution if tellurium is present. This is a very delicate test.

4. *Heating on Charcoal.*—Heated B.B. on charcoal, tellurium and the tellurides form a white sublimate near the assay, resembling somewhat antimony oxide. A brownish coating of unoxidized tellurium is usually formed on the coal just beyond the white sublimate. The sublimate volatilizes when heated B.B., and gives a pale bluish-green flame color when the R.F. is used.

5. *Open-tube Test.*—A white smoke of tellurium dioxide, TeO_2, forms when tellurium or tellurides are heated in the open tube. This condenses mostly on the tube near the heated part. The TeO_2 volatilizes slowly and fuses to globules, which are yellow when hot and colorless when cold.

6. *Closed Tube.*—Tellurium volatilizes when heated in the

closed tube, and deposits on the tube in the form of black globules having a metallic luster. A little TeO_2 is also usually formed by combination with the oxygen in the tube.

Thorium, Th—232.4 (see Rare Earths, p. 55)

Tin, Sn—118.7

1. *Reduction on Charcoal.*—Tin may be easily reduced to a metallic state from its minerals, by following closely the following directions: Mix 4 or 5 cmm. of *finely* powdered mineral with an equal volume of charcoal and two volumes of sodium carbonate, moisten with water, and heat B.B. on charcoal in a strong R.F. A large number of minute globules will form, if tin is present, and these can be easily collected into one. The globules are bright while in the R.F., but become quickly covered with a coating of oxide when exposed to the air. Some tin volatilizes when strongly heated, and deposits as a coating of oxide, SnO_2, on the coal about the assay. This oxide is a very pale yellow when hot but white when cold. It is not volatile in the O.F. and but very slowly in the R.F. The globules are very easily fusible and stay molten for some time on the coal. They are malleable, and if placed in a little cavity on charcoal and heated B.B., will yield, not only a coating on the coal, but may be imbedded in a thick, white crust of SnO_2, which does not volatilize or melt, and glows brightly. The oxide, if moistened with cobalt nitrate and ignited, turns green. The globules, when boiled in fairly strong nitric acid, form a white insoluble compound, metastannic acid.

2. *Oxidation with Nitric Acid.*—Sulphides containing tin dissolve in nitric acid with the formation of a white powder, metastannic acid.

Titanium, Ti—48.1

1. *Reduction with Tin.*—This test is not applicable to substances containing less than 3 per cent of titanium; for these §2 must be used. Fuse thoroughly 4 or 5 cmm. of *finely* powdered

mineral with five or six volumes of sodium carbonate on charcoal B.B. Pulverize the fusion, dissolve in hydrochloric acid, add a piece of metallic tin, and boil. Filter, if necessary, to remove suspended charcoal. If titanium is present the solution will show a violet color. It may be necessary to boil the solution down to a small volume before the color appears if the amount of titanium is small. The sodium carbonate forms sodium titanate, Na_4TiO_4, which dissolves in the hydrochloric acid, forming titanium tetra-chloride, $TiCl_4$. This is reduced by the action of the tin to the tri-chloride, $TiCl_3$, to which the violet color is due. This test very often fails because the mineral was not sufficiently decomposed during the fusion. This usually is due to the fact that the powder was not fine enough, or that the fusion was incomplete. Minerals which cannot be decomposed with sodium carbonate, like the niobates and tantalates, may be fused with borax.

2. *Test with Hydrogen Peroxide.*—This test is an exceedingly delicate one and is applicable to all minerals containing titanium. Fuse the mineral with sodium carbonate as directed under § 1. Dissolve the fusion in 1 cc. of concentrated sulphuric acid and 1 cc. of water, and heat until the solution becomes clear. Cool, dilute with water and add a little hydrogen peroxide. This gives a straw-yellow to deep amber color, depending on the amount of titanium present.

3. *Salt of Phosphorus Bead.*—In the O.F. the bead, well saturated with powdered mineral, is yellow when hot, colorless when cold. In the R.F. it is yellow when hot, and on cooling shows a delicate violet color. The test, however, is not very satisfactory, as it is apt to be interfered with by other substances.

Tungsten, W—184

1. *Some* **tungstates** *are decomposed* by boiling with hydrochloric acid, with the separation of a canary-yellow oxide of tungsten, WO_3. If a piece of granulated tin is boiled in such a solution a blue color is obtained, due to a partial reduction

($2WO_3+WO_2$) of the trioxide. On long-continued boiling the solution becomes brown, owing to reduction to WO_2.

2. **Tungstates,** which are *unaffected by acids,* may be decomposed by fusing with five or six volumes of sodium carbonate. The fusion is pulverized and boiled in a test-tube with 5 to 10 cc. of water. Sodium tungstate, which is formed by the fusion, goes into solution and is separated from the bases by filtering. The filtrate, acidified with hydrochloric acid, yields a white precipitate of tungstic acid, which turns yellow on boiling if a fair amount of tungsten is present. This precipitate boiled with metallic tin yields the characteristic blue color. This is a very delicate test.

3. *The Salt of Phosphorus Bead* is not colored by tungstic oxide in the O.F., but in the R.F. assumes a fine blue if the bead has been saturated with finely powdered material.

Uranium, U—238.2

Uranium is a rare element which occurs in only a few minerals. The colors which it imparts to the salt of phosphorus bead generally serve to identify it. When other substances are present, which also color the bead, the uranium must be separated by wet methods, and then may be tested in the bead.

1. *Salt of Phosphorus Bead Test.*—With a medium or large amount of material the bead in the O.F. is yellow while hot, but becomes yellowish-green on cooling. Heated in the R.F. the bead is a smoky or dirty green while hot, changing to a fine green when cold. The colors imparted to the borax bead resemble those imparted by iron, and are not, therefore, very reliable.

2. *Separation of Uranium in the Wet Way.*—First dissolve the mineral in hydrochloric acid (if insoluble, it may be first decomposed by fusion with sodium carbonate, or if not readily effected by this flux, borax may be used), and almost neutralize the solution with ammonia, after which, solid ammonium carbonate is added, together with a few drops of ammonium sulphide. The solution is well shaken and allowed to stand a few minutes.

By this process the uranium is retained in solution, while iron and many other elements with which it is apt to occur are precipitated. After filtering, the filtrate is acidified, boiled to expel carbon dioxide, and ammonia added in excess. The precipitated uranium should then be collected on a filter and tested in the salt of phosphorus bead, according to § 1.

Vanadium, V—51

1. *Bead Reactions.*—Vanadium is most conveniently detected by the color it imparts to the fluxes, particularly the salt of phosphorus.

		BORAX	SALT OF PHOSPHORUS
		MEDIUM TO LARGE AMOUNT OF MATERIAL	
Oxidizing Flame	HOT	Yellow	Yellow to Deep Amber
	COLD	Yellowish-green to Colorless	Paler than above
Reducing Flame	HOT	Dirty Green	Dirty Green
	COLD	Fine Green	Fine Green

The amber color in the O.F. with salt of phosphorus serves to distinguish vanadium from chromium.

Where other substances are present which color the fluxes and interfere with the test, the mineral to be tested may be fused in a platinum cup with four volumes of sodium carbonate and two of potassium nitrate, the fusion digested in warm water to dissolve the alkali vanadate formed, filtered, and the filtrate slightly acidified with acetic acid. Lead acetate added to this solution, if vanadium is present, will throw out a light yellow precipitate of lead vanadate. (Lead chromate, p. 37, is much more yellow.) The precipitate may be tested in the salt of phosphorus bead.

2. *Wet test for Vanadium.*—Vanadium forms vanadyl salts of the type of diovanadyl-sulphate $V_2O_2(SO_4)_2$ in which the state of oxidation is represented by V_2O_4. If a solution of divanadyl sulphate is treated with Na_2CO_3 or NH_4OH, avoiding an excess, a grayish-white precipitate separates. Vanadates are not thus precipitated. This precipitate dissolves in acids, yielding a blue color, but in alkalies yields a brown color.

The colorless or light yellow solutions of meta-, pyro- and ortho-vanadates are colored intensely orange by the addition of acids.

If H_2S is conducted into a strongly ammoniacal solution of a vanadate or hypovanadate, the solution at first turns yellowish red, then the color slowly deepens and finally becomes a characteristic, brilliant, violet-red color when the solution becomes thorougly saturated with H_2S. This is a very delicate test.

In acid solution, H_2S produces no precipitate, but reduces vanadic compounds to the divanadyl condition, which gives a blue color. Alcohol, oxalic and tartaric acids do likewise.

If a few drops of hydrogen peroxide are added to an acid solution of a vanadic salt, and the solution shaken, it becomes a reddish-brown.

Lead acetate precipitates vanadic acid quantitatively as a yellowish lead vanadate, $Pb_3(VO_4)_3$. If dilute HNO_3 is present, the similar lead chromate is not precipitated (see § 1 above).

Water

Water is given off from many minerals when these are heated more or less intensely. Its detection is often important in the determination of a mineral species. In testing for water, a few small fragments, or a little coarse powder (never fine), are shaken down into the bottom of a closed tube and heated, first gently and then more intensely, finally using the hottest blowpipe flame attainable, or even a blast lamp. The water condenses in the cool part of the tube. If only a slight ring of moisture is seen it does not indicate that water is an essential constituent.

Where the water is not chemically combined, but is held as "water of crystallization" (illustrated by gypsum $CaSO_4 \cdot 2H_2O$) it is expelled at relatively low temperatures, and may even begin to come off at a little above 100° C. Minerals such as Brucite, $Mg(OH)_2$, which contain hydroxyl, usually require a higher temperature to expel the water. In some instances a bright red heat, maintained for some time, is required to expel all the water.

Acid Water.—The hydrous salts of certain volatile acids with weakly basic elements, such as iron, aluminium, copper, and zinc, are decomposed in the closed tube, and yield water which is acid (detected with litmus paper). Certain minerals containing fluorine and hydroxyl also give off acid water in the closed tube.

Zinc, Zn—65.4

1. *Heating alone on Charcoal.*—If a fragment or the powder of a zinc mineral is heated intensely in the reducing flame on charcoal, a small coating of zinc oxide deposits near the assay. As a rule, the first indication of a coating seen is an *iridescent, purplish film* deposited just beyond the spot where the flame strikes the coal. On continued heating a *pale yellow* coat deposits which fades out white on cooling. It is not volatile in the O.F., but is slowly volatile in the R.F. The coating moistened with cobalt nitrate solution and reheated B.B. turns green. This coating is easily obtained with the sulphide and carbonate of zinc, but is more difficult to secure with the silicates. In order to get the oxide, the metal zinc must be reduced from the compound, hence the intense heating in the R.F. required. The metal

volatilizes readily, burns in the air to the oxide, and settles on the coal. Globules of zinc are *never* obtained (difference from tin and lead). The coating is generally obtained with the aid of soda more satisfactory than without it, and it is always so with the silicates.

2. *Reduction with Sodium Carbonate and Charcoal.*—Mix a small amount of finely powdered mineral with an equal volume of sodium carbonate and a little charcoal dust, moisten to a paste with water, and heat strongly in the R.F. The coat of ZnO obtained is the same as described above, but is generally heavier.

3. *Reaction with Cobalt Nitrate.*—When *infusible light-colored* zinc minerals, except silicates, are moistened with cobalt nitrate and heated strongly in the O.F. they assume a green color. This can be done with fragments in the forceps, but it is much better to use the powdered mineral on charcoal.

Silicates of zinc when treated in this way assume a *blue color,* usually with some green. It is due to the formation of a fusible cobalt silicate (?).

Zirconium, Zr—90.6

1. *Turmeric Paper Test.*—This is the only short test for zirconium, and yields fairly satisfactory results with minerals rich in zirconium. For small quantities more elaborate analytical methods must be employed. Powder the mineral finely and fuse *thoroughly* with five to six volumes of sodium carbonate, dissolve the fusion in hydrochloric acid and introduce into the solution a piece of turmeric paper, which will turn an orange color if zirconium is present. It is best, for the sake of comparison, to have a piece of turmeric paper in another test-tube, containing hydrochloric acid of about the same strength as the first.

2. *Behavior in Solution.*—Ammonium, sodium, and potassium hydroxides throw down zirconium from its solutions as a bulky white precipitate resembling aluminium and beryllium hydroxides, but differing from these in not dissolving in an excess of potassium hydroxide. If such a precipitate be filtered off, washed, dis-

solved in hydrochloric acid, and evaporated until only a drop or two remains, the residue, taken up in water, will either not yield a precipitate when oxalic acid is added, or will give one which goes readily into solution again (difference from the cerium metals, page 55).

CHAPTER III

TABULATED LISTS OF REACTIONS, ETC., USEFUL IN DETERMINATIVE MINERALOGY

I. Fusibility Scale, see page 6

II. Metallic Globules and Magnetic Masses

Gold.—Bright when hot or cold. Color yellow. Quite easily fusible. Malleable. Gives no coating on charcoal.

Silver.—Bright when hot or cold. Color white. Quite easily fusible. Malleable. Gives no distinct coating on charcoal.

Copper.—Bright when hot. Surface black when cold. Color red. Not easily fusible. Malleable. Gives no coating on charcoal.

Lead.—Bright in the R.F., iridescent in O.F. Dull surface when cold. Color lead-gray. Easily fusible. Soft and malleable. Yellow volatile coating of PbO on charcoal.

Bismuth.—Bright in R.F. Surface dull when cold. Color gray. Easily fusible. Rather brittle on flattening with hammer. Yellow volatile coating of Bi_2O_3 on charcoal.

Tin.—Bright in R.F., dull surface on cooling. Color white. Very easily fusible. Soft and malleable. White nonvolatile coating of SnO_2 on charcoal.

Easily fusible, bright metallic globules are often obtained by heating compounds of the metals with the volatile elements, sulphur, arsenic, or antimony. They are usually distinguished from pure metals by their extreme brittleness.

Magnetic globules or magnetic masses are obtained in the R.F. when iron, and sometimes when nickel and cobalt are present.

III. Closed Tube Reactions

(a) *Residues in Closed Tube*

Original Color	Color after Heating	Substance
green or blue.	black.	copper minerals..
green or brown.	black.	iron minerals.
pink, red, brown.	black.	manganese or cobalt minerals.
white or colorless.	dark yellow to orange or brown when hot; yellow to white cold	lead and bismuth minerals.
white, yellow or colorless.	pale yellow hot, white cold.	zinc minerals.

(b) *Gases in Closed Tube*

Color	Composition	Remarks
Colorless.	Carbon dioxide.	White ppt. with $Ba(OH)_2$. Odorless.
Colorless.	Sulphur dioxide.	Sharp irritating odor.
Colorless.	Oxygen.	Odorless.
Colorless.	Hydrofluoric acid.	Etches the glass. Sharp odor.
Reddish-brown color.	Nitrogen dioxide.	Disagreeable odor.
Reddish-brown color.	Bromine.	Very irritating odor.
Violet-colored vapor.	Iodine.	Irritating odor.
Brown smoke.	Organic material	Empyreumatic odor.

(c) *Sublimates in Closed Tube*

Color.	Composition.	Remarks.
Colorless.	Water, H_2O.	Liquid, volatile.
Pale yellow to colorless.	Tellurium oxide, TeO_2.	Liquid when hot, whitish globules when cold. Slowly volatile.
Yellow to reddish.	Sulphur, S.	Liquid when hot, *yellow* crystalline solid when cold. Volatile. May be nearly white when the amount is small.

Color.	Composition.	Remarks.
Red	Oxysulphide of Antimony.	Black when hot.
Deep red to nearly black.	Sulphides of Arsenic.	Liquid when hot. *Reddish-yellow* transparent solid when cold. Volatile.
Black or brown.	Tarry products.	Liquid.
Black mirror.	Oxysulphide of antimony, Sb_2S_2O.	Slowly volatile. Black when hot, *dark red* when cold.
Black mirror.	Arsenic, As.	Gives garlic odor if heated after breaking tube.
Black mirror.	Mercuric Sulphide, HgS.	Volatile. The sublimate rubbed very fine, becomes red.
Black globules.	Tellurium, Te.	Fusible globules.
Gray globules.	Mercury.	Globules may be united by rubbing.
Gray, metallic mirror.	Arsenic.	Obtained when As is abundant. Garlic odor if tube is broken and heated.
White, solid.	Chlorides of lead and oxides of antimony, and arsenic.	These are usually rather slight sublimates.

IV. Open Tube Reactions

Odors Obtained in Open Tube. Gases, Vapors

Odor of Burning Sulphur.—Strong pungent odor due to the formation of sulphur dioxide SO_2. Gas bleaches moistened litmus paper held in end of tube. Very delicate test.

Odor of Arsenic (garlic odor).—Obtained when arsenic is driven off rapidly and incompletely oxidized.

Odor of Selenium.—A peculiar, nauseating smell (decaying horse-radish odor) obtained from volatilized and incompletely oxidized selenium.

Odor of Osmic Oxide.—An exceedingly pungent odor—poisonous if too much is inhaled.

Table of Sublimates

Color.	Composition, etc.	Remarks.
Black.	Oxysulphide of antimony.	Black when hot, red, cold. Slowly volatile.
Black.	Arsenic and sulphide of mercury.	Volatile. Results from too rapid heating (see closed tube sublimates of arsenic, antimony, and sulphur compounds).
Red, orange, yellow, sometimes mixed with white.	Sulphides of arsenic. Sulphur.	The arsenic compounds are redder than sulphur and do not fade as much. Result from too rapid heating.
Red.	Oxysulphide of antimony.	Black when hot. Slowly volatile.
Red.	Selenium.	Volatile. With selenious oxide, see below.
Pale yellow when hot; **white** when cold.	Oxide of mloybdenum, MoO_3.	Generally clouds the tube for some distance. Often crystalline.
White, crystalline.	Arsenic oxide, As_2O_3.	Octahedral under the microscope. **Very volatile.**
White.	Selenium oxide, SeO_2.	Often with red, finely divided selenium. Crystalline prismatic. Volatile.
White to pale yellow.	Tellurium oxide, TeO_2.	Slowly volatile.
White.	Antimony oxide, Sb_2O_3.	Usually as a ring near assay. U. powdery, some times cryst. See next below. Slowly volatile.
Pale, straw-yellow when hot, white when cold.	Antimonate of antimony.	Follows along the tube like a heavy smoke. Infusible, non-volatile, powdery. Always obtained with Sb_2O_3 when sulphur is present.
White.	Sulphate and sulphite of lead.	Non-volatile, infusible. Obtained from sulphide of lead on rapid heating.
Gray.	Mercury, Hg.	Volatile. May be united into globules by rubbing.

Residues in Open Tube

Orange to **red** when hot, **yellow** to **pale yellow** when cold.	Oxide of lead.	Liquid when hot. Obtained from roasting sulphides or carbonate.
Dark red.	Oxide of iron, Fe_2O_3.	Obtained from long roasting of sulphides, etc.
Black.	Oxides of iron, manganese, copper and cobalt.	Obtained from long roasting of sulphides, etc.
Yellow-green.	Oxide of nickel.	Obtained fron long roasting of sulphides, etc.

V. Sublimates on Charcoal

Color	Substances	Remarks
White.	Arsenic oxide, As_2O_3.	Very volatile. Deposits distant from assay. U. accomp. by garlic odor.
White; red without, **steel-gray** within.	Selenium oxide, SeO_2. The red is Se.	Very volatile. Imparts a blue color to R.F. Peculiar odor of selenium (like decaying horse-radish).
White, on outside **gray** slightly **brown.**	Tellurium oxide, TeO_2. The gray is Te.	Dense, volatile. Heated in R.F., volt, and gives bluish-green flame color.
White, bluish on outside.	Antimony oxide, Sb_2O_3.	Dense, volatile. Deposits quite near the assay.
White.	Lead chloride; rarely chlorides of copper and mercury.	Volatile. U. deposits distant from assay. Bluish flame color.
Canary-yellow when hot, **white** when cold.	Oxide of zinc, ZnO.	Not volatile in O.F. Deposits near assay. Moistened with cobalt and ignited, turns green.
Faint yellow when hot, **white** when cold.	Oxide of tin, SnO_2.	Not volatile in O.F., diff. volatile in R.F. Moistened with cobalt nitrate and ignited turns green.
Pale yellow when hot, **white** when cold. **Bluish** on outside, **inside** a **copper-red.**	Oxide of molybdenum, MoO_2. Copper red coating is MoO_2.	Volatile in O.F. Touched with R.F., turns to a fine deep blue. Obtained from heating MoS_2 in strong O.F.

Color.	Substance.	Remarks.
Pale yellow to white, may be mixed with **blue; copper red** nearer assay.	Oxides of molybdenum.	Obtained when MoS_2 is heated in the R.F.
Yellowish to brownish coat mixed with and bordered with white.	Sulphide and oxide of arsenic mixed sometimes with arsenic.	Very volatile. Obtained when sulphides of arsenic, with or withwithout other metals, are heated rapidly.
Yellow when hot, **straw-yellow** when cold; dense **white,** with **bluish** border distant from assay.	A mixture of lead oxide, lead sulphite and sulphate (?).	Volatile in both flames. Resembles antimony. Obtained from heating sulphides of lead rapidly.
Dark yellow when hot, **sulphur-yellow** when cold, **white** or **bluish white** on outside.	Oxide of lead, PbO.	Slowly volatile in bloth flames. Moistened with hydriodic acid and heated in O.F. a yellowish-green lead iodide is formed.
Dark orange-yellow when hot, yellow to orange-yellow when cold.	Bismuth oxide, Bi_2O_3.	Slowly volatile in both flames. Moistened with hydriodic acid, and heated gives a reddish to chocolate-brown coat of bismuth iodide.
Reddish to deep lilac.	Silver when accompanied by lead and antimony.	May be obtained when small amounts of silver minerals are present with sulphides of antimony, lead, and zinc.
Reddish-brown; yellowish distant from assay.	Cadmium oxide.	U. very slight.
Purplish, iridescent coat.	Small amounts of cadmium or zinc oxide.	U. very slight and often obtained from zinc minerals before the ZnO deposits; often borders the latter.

VI. Table of Sublimates as Obtained on Plaster Tablets (see p. 12)

Only sublimates are listed here that are equally or *more* characteristic than those similarly obtained on charcoal.

Element.	Character of sublimate.
Selenium.	Brick-red to crimson.
Tellurium.	Deep brown coat.
Cadmium.	Dark brown coat shading to greenish-yellow and again to dark brown.
Molybdenum.	Similar to that on charcoal, perhaps more striking.

VII. Table of Sublimates Obtained on Plaster and on Charcoal With the Aid of Hydriodic Acid or Bismuth Flux (see p. 12)

Element	Character of sublimate
Lead.	On Charcoal—Greenish-yellow. Plaster—Chrome-yellow.
Bismuth.	Charcoal—Bright red band with fringe of yellow. Plaster—Chocolate-brown with underlying scarlet. With ammonia becomes orange-yellow and later cherry-red.
Mercury.	Charcoal—Faint yellow. Plaster—Scarlet with yellow if slowly heated.
Antimony.	Charcoal—Faint yellow. Plaster—Orange mixed with peach-red.
Tin.	Plaster—Brownish-orange.
Selenium.	Plaster—Reddish-brown, nearly scarlet.
Tellurium.	Plaster—Purplish-brown with dark border.
Molybdenum.	Plaster—Ultramarine-blue.

VIII. Bead Reactions

In the following tables many bead reactions usually given have been omitted in the belief that they are as a rule indecisive and often misleading. Only reactions are listed here that are characteristic, provided the test has been performed as directed on page 16. Below, under the heading, Substance, the word accompanying the name refers to the relative amount of powdered oxide that is required to produce the colors given in the same horizontal column. By "**small**" is meant a very minute amount —a few specks; by "**medium**" is meant, say 0.5 cmm., by "**large**" 1 cmm. up. This is, of course, only a very rough way of indicating the amounts to be used, but it will perhaps, serve its purpose. It must be borne in mind that the colors listed below are those yielded by *pure oxides.* Variations of color, impossible to describe, may be obtained from mixtures of various elements, each one of which gives a color reaction.

BORAX BEADS

OXIDIZING FLAME			REDUCING FLAME	
Hot	Cold	Substance	Hot	Cold
pale yellow	nearly colorless	**Titanium,** medium	grayish	pale violet
yellow	nearly colorless	**Iron** or **Uranium,** medium	pale green	nearly colorless
yellow	yellowish-green	**Chromium,** small	green	green
yellow	very pale yellowish-green	**Vanadium,** medium	smoky green	green
yellow	pale yellow	**Cerium,** medium		
deep yellow to orange-red	yellow	**Uranium,** medium to large	pale green	pale green to nearly colorless
deep yellow to orange-red	yellow	**Iron,** large	bottle-green	fades some on cooling
deep yellow to orange-red	yellowish-green	**Chromium,** medium to large	green	fine green
pale green	blue-green	**Copper,** medium to large	colorless to green	opaque red with large amount
pale green	pale blue-green	**Copper,** small	nearly colorless	
green	yellow, green, blue	Mixtures of Fe, Cu, Ni and Co		same or opaque
blue	blue	**Cobalt,** small	blue	blue
violet	reddish-brown	**Nickel,** medium	opaque gray	opaque gray
violet	reddish-violet	**Manganese,** small	colorless	colorless

SALT OF PHOSPHORUS BEADS

OXIDIZING FLAME			REDUCING FLAME	
Hot	Cold	Substance	Hot	Cold
yellow	colorless	**Titanium,** medium to large	yellow	violet
pale yellow	colorless	**Tungsten,** large	dirty blue	fine bluish
yellow	pale yellow	**Vanadium,** small	pale smoky green	green
yellow to deep yellow	colorless	**Cerium,** medium	colorless	colorless
yellow	pale yellowish-green	**Uranium,** medium	pale smoky green	fine green
yellowish-green	colorless	**Molybdenum,** medium	smoky green	fine green
deep yellow to brownish-red	yellow to colorless	**Iron,** medium to large	red, yellow to yellow green	almost colorless
deep yellow to deep amber	yellow	**Vanadium,** medium to large	smoky green	fine green
reddish to brownish-red	yellow to reddish yellow	**Nickel,** medium	reddish to brownish-red	yellow to reddish-yellow
green	pale blue	**Copper,** small	pale yellow-green	pale blue to nearly colorless, rarely red
dark green	blue or blue green	**Copper,** medium to large	brownish-green	opaque red
green	yellow, green, blue	Mixtures of Fi, Cu, Ni and Co		
smoky green	fine green	**Chromium,** medium	smoky green	fine green
blue	blue	**Cobalt,** medium	blue	blue
grayish-violet	violet	**Manganese,** small	colorless	colorless

SODIUM CARBONATE BEADS

In the O.F. *chromium* colors the sodium carbonate bead a pale yellow when cold.

Manganese even in small amounts imparts a bluish-green color to the cold bead.

In the R.F. soda beads, if colored at all, are generally black, brown, or gray, and are not distinctive.

IX. Colors Obtained by Heating B.B. with Cobalt Nitrate Solution

Fragments may be used, but the fine powder made up into a small pile on charcoal, moistened with the cobalt nitrate and then **intensely** ignited B.B. gives a more reliable result.

Color.	Substance.	Remarks.
Blue.	**Infusible Aluminium** minerals which are light colored or white, or become white on heating B.B.	The powder or a fragment requires very intense ignition as a rule.
Blue.	**Infusible silicate of zinc.**	
Green or bluish green.	Oxide of **tin.**	Applies to coating on charcoal.
Green.	Oxide of **zinc**; zinc minerals except the silicates.	Strong O.F. is usually required. and color does not show well until cold.
Dirty Green.	Oxide of **antimony**	These colors, if obtained at all, are U. indecisive.
Pale pink or flesh color.	**Magnesian** oxide	
Lavender.	**Berryllium** oxide	

X. Flame Colorations

Color	Element.	
Crimson	Lithium	May be rendered yellowish by contamination with sodium.
Crimson	Strontium	
Yellow-red	Calcium	
Yellow	Sodium	
Yellowish-green	Barium	
Yellowish-green	Molybdenum	
Bright green, slightly yellowish	Boron	
Pale green	Tellurium	
	Antimony	
	Lead	
Emerald-green	Copper oxide, and iodide	
Pure green	Thallium	
Pale bluish-green	Phosphorus	
Bluish-green (flashes)	Zinc	
Bluish-green	Tellurium	
Pale blue	Arsenic	
Azure-blue	Selenium	
Pale azure-blue, tinged with green	Lead	
Azure-blue	Chloride of copper	
Pale violet	Potassium	Use a blue glass to cut out sodium

XI. Colored Solutions Obtained from Minerals with Acids

Color.	Acid.	Elements and Remarks.
Yellow to deep yellow or orange	HCl	Ferric iron
Yellow to brownish	HCl	Higher oxides of manganese. Odor of chlorine
Pink to pale-rose	HNO_3	Cobalt. Turns brown then reddish on addition of excess of NH_4OH.
Pale green	HNO_3	Nickel turns blue on addition of excess of NH_4OH
Green or bluish-green	HNO_3 HCl	Copper, turns deep blue upon addition of excess of NH_4OH.
Blue-green	H_2SO_4	Same as next above

XII. Residues Obtained in Acid Solutions of Minerals

White Powdery.—Silica.—Obtained from many silicates when boiled with acids. These are all non-metallic in luster.

White Powdery.—$PbSO_4$, $SbO_2(OH)$, SnO_2. Obtained from a number of metallic sulphides containing either lead, antimony, or tin, when treated with conc. HNO_3.

Yellow, Powdery.—Obtained from **tungsten** minerals with HCl. Turns blue when boiled with tin.

Yellow, spongy masses, or melted globules of **sulphur** are obtained when certain sulphides are boiled in nitric acid.

Gelatinous Mass.—Silicic acid.—Colorless to yellow. Obtained on evaporation of the acid solutions of many silicates.

CHAPTER IV

THE DETERMINATION OF MINERALS, USE OF TABLES, ETC.

General Remarks.—No special method of procedure can be laid down for the determination of minerals. The experienced mineralogist can usually recognize at sight the more common or important species, or at least will need to make only one or two simple tests to render certain their identification. In the case of the less common species, or of common ones of unusual appearance and habit, he may have resort to a more careful examination involving a determination of the physical and chemical properties, and in so doing may have to employ microscopic methods and use polished surfaces or thin slices. In all such work it is usually necessary to refer to standard textbooks of mineralogy [1] in which are collected, in a systematic manner, the data regarding the various mineral species and their varieties. He is, furthermore, often greatly aided in such an examination by the use of " determinative

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[1] The following is a list of books in English on Descriptive Mineralogy:

A System of Mineralogy (encyclopedic), by James D. and E. S. Dana. John Wiley & Sons, Inc. Also Appendices Nos. 1, 2 and 3.
Dana's Textbook of Mineralogy, Third Edition, by W. E. Ford. John Wiley & Sons, Inc.
Study of Minerals and Rocks, by A. F. Rogers. McGraw-Hill Book Co.
Mineralogy, Etc., by A. J. Moses and C. L. Parsons. D. Van Nostrand Co.
Mineralogy, by E. H. Kraus and W. F. Hunt. McGraw-Hill Book Co., Inc.
Mineralogy, by A. H. Phillips. Macmillan Co.
Mineralogy, by W. S. Bayley. D. Van Nostrand Co.
Mineralogy, by H. A. Meirs. Macmillan Co.

tables[1]" in which the various minerals are arranged according to some carefully arranged scheme.

The beginner, or worker of small experience, will in general save much time and effort, and arrive at a satisfactory result with greater certainty, if he uses one of these "determinative" tables, *supplemented always by reference to a reliable, descriptive text.*

Of those tables which do not involve the use of the microscope with polished surfaces or thin slices, it may be said that they fall under three types.

In the first, the distinction between the different minerals is based entirely, or very largely, on the physical properties, such as color, hardness, streak and crystalline characters, etc. If chemical and blowpipe characters are used, they are given a very subordinate place. Such tables are often useful where pure and easily isolated minerals are in question, particularly where the mineral is seen to possess some striking and easily distinguished character, such as a simple crystal form or cleavage. They minimize or ignore the equally important blowpipe or chemical properties, which are usually quite easily ascertained, and as a rule, with somewhat greater certainty by the average student of min-

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[1] Books on Determinative Mineralogy are:

Determinative Mineralogy and Blowpipe Analysis, by G. J. Brush and S. L. Penfield (most complete work of its kind). John Wiley & Sons, Inc.

Determinative Mineralogy, by A. S. Eakle. John Wiley & Sons, Inc. (By Physical Properties.)

Tables for the Determination of Minerals, by P. Frazer and A. P. Brown. J. B. Lippincott Co.

Most of the Descriptive texts listed above contain more or less extensive determinative tables.

For the determination of opaque minerals by means of the reflecting microscope:

Microscopic Examination of Ore Minerals, by W. Myron Davy and C. M. Farnham. McGraw–Hill Book Co., Inc.

For the Determination of Minerals with the polarizing microscope:

Determination of the Rock-forming Minerals, by Albert Johannsen. John Wiley & Sons, Inc.

Petrographic Methods, Part II, by Dr. E. Weinschenk, translated by R. W. Clark. McGraw–Hill Book Co., Inc.

Elements of Optical Mineralogy, etc., by N. H. and A. N. Winchell. D. Van Nostrand Co.

erals. This is particularly true with the run of ordinary mineral material as it comes from the mineral deposits, and with such the purely physical determinations commonly lead to inconclusive or erroneous results. They are perhaps, useful as a means of acquainting students with minerals when carefully selected material is given them, and where there is plenty of time for such methods of instruction.

The second type, lays the first and main emphasis on the diagnostic value of blowpipe and chemical properties, and uses the physical properties for making the final distinctions between chemically similar minerals. This form of table gives, in general, more reliable results than the first type. The objection to it is that in many instances it subordinates obvious, or easily determinable physical properties, which if used first as a means of differentiation, might render very simple and rapid a determination that otherwise is long and tedious.

The third type aims to give appropriate weight to both kinds of properties as occasion arises. The table which follows (III) is of this type. In it are listed the common and important mineral species. The rarer species and subordinate varieties are not listed in many cases, but references are given to the more comprehensive tables of Brush and Penfield. Indeed with the majority of minerals listed it is expected that a descriptive text will be consulted for final confirmation, for only by so doing is it possible to avoid the chance of serious error in determination.

The following observations should be carefully heeded by the student of mineralogy. The first thing to do in determining a mineral is to examine it thoroughly with **the eye alone and with a pocket lens.**[1]

This examination should furnish information regarding such matters as color, structure, crystallization and cleavage, whether the material appears to consist of one substance or more than one, and, if the latter, what relation the different ones have to each other as regards occurrence.

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[1] A lens with a flat field and of about one inch focus is recommended. For fine-texture material a simple binocular microscope is most useful.

The **hardness** and **streak** may then be tested for.

A small fragment should next be tested B.B. first in the forceps, and then alone on charcoal, and results noted. Further tests with closed and open tubes, or with beads, or acids, may next be carried out, but, in general, time may be saved, and the final result reached quite as quickly, and more safely, by referring to the determinative scheme as soon as the forcep andcharcoal tests B.B. have been carried out. If, however, some very distinctive crystal form or cleavage can be clearly and certainly made out, reference to Tables I or II may be made at once, although in general confirmatory tests **have** to be made by beginners, and not much time, if any, is gained in this way.

The same may be said regarding a striking color, streak, or structure, and, if such exist, use may be made of some of the one tables which are to be found in most of the textbooks. In the writer's experience, however, if a reliable and speedy determination is desired, the most satisfactory procedure is to follow out Table III with later reference (if necessary) to Brush & Penfield's standard work, a copy of which should always be available.

In using Table III it will be noted by an inspection of the "**Key**" that the first differentiation is made on the basis of the character of the **streak.** Division A contains those minerals which yield **black** or **dark colored** streaks. Division B contains those with **white** or **light colored** streaks. The few minerals with streaks intermediate between light and dark are listed under both divisions.

The term **Streak** is here used to designate the color of the **very fine powder.** The streak may usually be obtained by rubbing the mineral on a piece of white unglazed porcelain or white whetstone (Arkansas Stone) and noting the color of the finely powdered material left on the plate. A good-sized streak should always be made when possible so that it can be clearly seen. It is always well to look at it through a lens also. Where very hard minerals are being studied, which scratch the streak-plate, small fragments should be powdered very fine, and the color of the powder noted. The powder, if at all dark, should be rubbed out thin on a piece of white paper to bring out the color.

Many minerals are metallic in character and these, like the common metals, are opaque to light and yield a streak which is either black or dark. If the mineral is soft, the streak will often show a distinct coloration, perhaps grayish or yellowish (galena or chalcopyrite for example), and possess a metallic sheen. This appearance is best seen if the streak is viewed at an angle. If viewed directly the same streak may appear black or nearly so. The streak should always be examined in both ways, and it should be noted that some of the discrepancies in the statements regarding the color of particular streaks in different textbooks, are due, in part at least, to these different ways of viewing the streak.

Minerals yielding such dark or metallic streaks are quite generally spoken of as having a **Metallic luster,** even when the mineral itself is dull in appearance and does not suggest what is ordinarily thought of as a metallic appearance.

Minerals which show a dark brownish or reddish, or other colored streak are somewhat transparent to certain wave lengths of ordinary light, and such are often referred to as being of **sub-metallic luster.**

The minerals which yield **white** or **light** colored streaks are transparent to light, at least in thin pieces, and seldom suggest anything metallic by their appearance, though many of them are highly lustrous, and may be dark colored in the specimen. They are often referred to as of **non-metallic luster,** and may in addition be described as of adamantine, vitreous, or other luster, according to their appearance. For a description of these lusters, as well as of color, a descriptive textbook should be consulted.

The subdivisions in the table are made on the basis of the mineral's behavior when heated B.B. on charcoal in Division I, and on the behavior in the forceps, or on charcoal B.B., in Division II.

Inspection of the "**key,**" and the succeeding tables, will make it clear as to how further differentiation is effected.

In using the tables it is necessary to work from the **beginning**

of the table eliminating each division successively. The **whole value** of the order of arrangement is **lost** if this is not done. For example, a certain mineral, cryolite, having a white streak, and fusing easily to a white enamel is **not found** in Division II, Subdivision D, Section *b*, because it not only fuses as stated, but gives an **alkaline reaction** and falls therefore, in the **preceding** Subdivision C, Section *b*. So, unless each division, subdivision, and section is eliminated in order, the one containing the mineral sought for may be passed by, and no determination, or a wrong one, made.

It is perhaps desirable to point out here, that where a mineral cannot be wholly freed from contaminating substances, or where isomorphous mixtures are being examined, some departure from the behavior of the ideally pure mineral is to be expected and must be allowed for where possible. Thus in certain Tetrahedrites (Division I, Subdivision A, Section *b*) a little arsenic may be present with the antimony and evidences of arsenic may appear during heating B.B. on charcoal. The main reaction is, however, for antimony, and this fact should be used in following out the determination. Or again, in Division II, Subdivision D, Section *b*, the mineral prehnite, when pure, fuses to a white glass, but if, as is often the case, a little iron oxide, or other iron mineral is present, a yellowish or brownish glass or slag is obtained. Provision is made in the tables for such irregularities where possible, but it is well to keep it in mind that due allowance must often be made for admixed material.

The determination of fine-grained minerals where several may be present together, or of coarser material which may contain inclusions of different nature from the main mass, necessarily presents difficulties and seriously limits, or restricts, the application of the methods here elaborated. The student must realize, as of course the experienced mineralogist does, that in very many instances examination by other methods must be resorted to, to supplement and confirm conclusions reached by the use of a table like the present one. With the metallic minerals a study of polished surfaces under the microscope is of the greatest service.

By this method of examination a variety of chemical, and some physical tests, can be applied to very small grains in a mixture, and distinctions of color and structure can be noted, that wholly escape the eye, unaided by the microscope. Often what appears to be homogeneous material is found to be in reality a mixture. Examination by such means is coming increasingly into use. With transparent minerals, examination with the polarizing microscope is the court of last resort, and in fact, with silicate minerals, particularly as they occur in the fine-grained or dense rocks, it is the only method of examination capable of yielding the information desired. The minerals are examined in the form of fine powders, or in carefully cut thin slices, their optical properties determined, and their structural relations ascertained.

No attempt has been made to make this table exhaustive. Many rare species are omitted. For some of these, reference is made to Brush and Penfield's "Determinative Mineralogy," but even here there are now a good many omissions of recently described species. If, in the process of determining a mineral, a careful study of the minerals listed in the final group where the mineral in question falls, shows that it does not correspond entirely with the minerals listed there, the appropriate place in Brush and Penfield's tables can easily be found, and if it is not finally located there, then enough data will have been collected so that with its help, the mineral may be located in Dana's "System of Mineralogy," or in some of the several appendices to that work, or, in some one of the summaries of newly described minerals to be found in recent numbers of the journals devoted to mineralogy.

It will perhaps be evident from what has been said that to determine mineral material is an art that requires no little knowledge and skill, good powers of observation, and the ability to draw conclusions correctly from observed facts.

No detailed description of the various structures that characterize minerals will be entered into here inasmuch as they are sufficiently described in the standard descriptive textbooks, and reference may be made to these. A few special remarks will, however, be made regarding **cleavage** and **hardness.**

Cleavage.—By the term **cleavage,** as applied to minerals, is meant the breaking or splitting, under the action of a blow or strain, along one or more directions which are parallel to definite crystal planes. These planes are directions of marked weakness in the crystal structure and usually follow those directions in the crystal which may be indicated by simple index relations such as the cube face, (100), a prism, (110), or a pinacoid (010). Where the cleavage is perfect, plane **reflecting surfaces** result.

In a specimen in which the individual crystals are of fair size, if it is broken carefully, it is sometimes possible, particularly if a lens or microscope is used, to pick out and identify definite cleavage forms, for example, cubes of galena, rhombohedrons of calcite, or rhombic plates of barite. Again, if only one or two cleavage directions exist, the relation which these bear to the natural crystal form may be ascertained. In general the presence of cleavage in a granular, more or less compact aggregate of crystals, is indicated on a broken surface by many reflecting planes at various inclinations which make the surface appear bright, particularly if it be turned at various angles to a source of light. Very minute crystalline structures can often be detected, if a lens or microscope is used, by noting the presence of reflecting planes (very fine granular galena or sphalerite for example), even though the precise nature of the cleavage cannot be told.

As some minerals possess no, or only very poor, cleavage, the absence of evident cleavage should not be taken to mean the absence of crystalline structure. Almost all minerals sometimes occur in massive and apparently noncrystalline form. Amorphous materials never show any natural cleavage.

In the tables, the system of crystallization and the cleavage are indicated by suitable abbreviated symbols, but these are given only in cases where it is believed that they are likely to be of practical value in identifying the mineral.

Hardness.—By the term hardness, as applied to minerals, is meant the relative resistance to abrasion, or scratching, offered by a smooth surface (preferably a smooth, natural crystal surface). The standards of comparison are certain substances which long experience has shown to be suitable for this purpose. Taken together they form a series of ten steps of differing degrees of hardness and are known as the **Hardness Scale.** It is as follows:

No. 1. Talc
2. Gypsum
3. Calcite
4. Fluorite
5. Apatite
No. 6. Orthoclase
7. Quartz
8. Topaz
9. Corundum
10. Diamond

The scale is entirely arbitrary: there is not even an approximation to uniformity in the differences of hardness between members of the scale. Indeed, there is evidence to show that the interval between 9 and 10 is probably greater than between 1 and 9. However, the scale is of much practical value.

In actual practice for ordinary work a shorter and simpler scale is often used, viz.,

The finger-nail	about 2.5
Steel	about 5.5
or glass	5.5 to 6
Quartz	7

Any mineral that can be scratched with the finger-nail may be classed as **very soft**; one that can be scratched by steel, but not with the nail, as **soft**; one scratched by quartz, but not by steel, as **hard,** and one not scratched by quartz, as **very hard.**

In testing for hardness, as smooth a surface as possible should be chosen, a good crystal face being the best surface. It is then ascertained by trial which mineral of the hardness scale will just **clearly scratch** the surface which is being tested. It is generally well to reverse the process and test surfaces of the hardness specimens with a corner or edge of the mineral whose hardness is to be found. Too much force should not be used, but a steady firm pressure should be exerted in drawing the one across the surface of the other. In attempting to scratch an irregular and rough surface, particularly a granular one, small fragments or grains may be broken out and crushed, often giving the impression that the material is softer than the testing edge, whereas it may have a true hardness which is greater. This can generally be told if a smooth surface of known hardness is carefully rubbed with the mineral (or with grains broken from it), and the surface examined with a lens for scratches.

In using a knife blade or other steel tool it will sometimes be found that it will scratch, or apparently scratch, a surface, while the same surface will scratch ordinary glass, and the latter is usually unscratched by steel. This illustrates again the fact, that hardness testing is far from an accurate method of testing. It is, nevertheless, a **most useful** one in practice.

There is sometimes a noticeable difference of hardness in different directions in crystals (example, cyanite).

Specific Gravity. — The specific gravity of a pure, homogeneous mineral material is a physical constant that can often be determined quickly and quite accurately, and is, therefore, one of considerable importance in the determination of minerals. When fragments, or crystals, weighing a gram or more, and of undoubted homogeneity, are available, a sufficiently good determination of the specific gravity can be made with one of the simple forms of specific gravity balances described in the text-books of mineralogy.

Such determinations are particularly useful when it is important, for any reason, not to impair or destroy the specimen. They are often useful as a means of confirming mineral identifications worked out by other methods.

In general, until the student has acquired considerable experience in mineral determination, he should seek the advice of his instructor before carrying out a specific gravity determination. Many useless and even misleading determinations may be made, and time wasted, unless due care is exercised regarding the character of the material and the particular method to be used.

For a description of the methods and apparatus used in determining the specific gravity, reference may be made to one of the standard text-books on mineralogy, particularly to Brush and Penfield's treatise, p. 232. For more refined methods, one of the more extended texts on experimental physics should be consulted.

Attention is here especially directed to the fact that certain liquids of high density ("heavy solutions") can be used to advantage in many instances for the determination of the specific gravity of minerals. The liquids are adjusted by dilution until the mineral grains, whose specific gravity is to be determined, are just suspended, (neither float nor sink), and then the specific gravity of the liquid, which is then the same as that of the mineral, is determined with a pycnometer.

The same liquids are often employed to separate minerals of different densities from one another. See B. & P., p. 238.

Magnetic Separation of *Minerals.*—Mixtures of two or more minerals may sometimes be crushed to a fine sand and separated by means of their different magnetic susceptibilities. A powerful electro-magnet, the strength of which can be regulated, is passed over the mineral sand spread out thinly on a glass plate. Those grains which are attracted with sufficient force are picked up and thus separated from the remainder. Magnetite may be easily and completely removed from a sample, using a very weak magnetic flux. Ilmenite, hematite and chromite may be picked by a stronger flux and thus separated from iron-bearing silicates such as garnet, hornblende, etc. The latter can be then separated from quartz and other non-magnetic minerals. The non-magnetic residue from such a treatment may then be further broken up into fractions by means of "heavy-solutions." The magnetic separation has proved very useful in the examination of natural sands and crushed mill-products.

TABLE I

Common Minerals Showing Very Distinct or Perfect Cleavage

Character of Cleavage.	Mineral.	
	Dark Streak. (Metallic Luster.)	**Light colored or white Streak.** (Non-metallic Luster.)
Cubic. I. Cleaves in three rectangular directions.	**Galena.**	**Halite.** Sylvite. Periclase.
Pseudo-Cubic. Not Isometric.		**Corundum** R. **Anhydrite.** O. **Cryolite.** M.
Octahedral. I. Cleaves in four equally inclined directions.	**Magnetite** (parting).	**Fluorite.** **Diamond.**
Dodecahedral. I. Cleaves in six directions making angles of 60°.	**Sphalerite.** (Black color.)	**Sphalerite.**
Rhombohedral. Cleaves in three equally inclined directions.		**Calcite.** **Dolomite.** **Magnesite.** **Rhodochrosite.** **Siderite.** **Ankerite.** **Corundum** (parting, nearly cubical).
Parallel to two inclined **Prismatic** directions, and another at right angles (Basal).		**Barite.** } Rhombic **Celestite** } fragments

TABLE I.—(*Continued*)

Parallel to two inclined **prismatic** directions.	**Enargite.** **Arsenopyrite.**	**Amphiboles.** M. Cleavage angle 124°.
Parallel to two directions at right angles.		The **Feldspars.** (∥ to 001 and 010.)
Parallel to one direction.	**Graphite** (basal). **Molybdenite** (basal). **Jamesonite** (basal). **Stibnite** (∥ to 010). **Bismuthinite** (∥ to 010). **Wolframite** (∥ to 010).	The **Micas** (Basal). The **Chlorites** (Basal). The **Brittle Micas** (Basal). **Talc** (Basal). **Topaz** (Basal). **Apophyllite** (Basal). **Pyroxene** (Basal parting).

TABLE II

Common Minerals which often Show Easily Recognized or Determinable Crystal Forms

A. Isometric Crystals.

- Cubes, or slightly modified cubes. Metallic Luster.—**Galena. Pyrite.** Cobaltite. Smaltite.
- Non-metallic.—**Fluorite. Halite.** Sylvite. Boracite. Cerargyrite. Periclase.
- Octahedrons, Metallic.—**Magnetite. Chromite.** Franklinite. Less commonly **Pyrite. Galena.** Perovskite.
- Non-metallic.—**Spinel. Cuprite.** Diamond.
- Dodecahedrons.—**Magnetite** (metallic). **Garnet. Cuprite.**
- Trapezohedrons.—**Garnet. Leucite. Analcite.**
- Pyritohedrons.—**Pyrite.** Cobaltite.
- Tetrahedrons.—**Tetrahedrite** (metallic). **Sphalerite.** Boracite. Diamond.

B. Tetragonal.

- Square Pyramids.—**Zircon. Wulfenite. Vesuvianite.** Octahedrite. Xenotime.
- Square Prisms.—**Zircon. Vesuvianite. Scapolite. Apophyllite.**
- Square Plates.—**Wulfenite.** Torbenite. **Apophyllite.**

C. Hexagonal.

- Hexagonal Pyramids.—**Quartz. Apatite. Corundum.** (Pseudo-hexagonal).—**Witherite. Cerussite.**
- Hexagonal Prisms.—**Quartz. Beryl. Calcite. Apatite. Pyromorphite.** Vanadinite. **Corundum.** Pseudo-hexagonal.—**Aragonite. Strontianite. Amphibole.**
- Hexagonal Plates.—**Graphite. Molybdenite.** Pseudo-hex.—**Micas.**
- Trigonal Prisms.—**Tourmaline.**
- Rhombohedrons.—**Calcite. Dolomite. Siderite. Ankerite. Rhodochrosite.** Chabazite.
- Scalenohedrons.—**Calcite.** Proustite.

D. Other Systems.

- Prismatic Crystals.—(Metallic). **Stibnite, O. Manganite, O. Arsenopyrite, O.** Pyrolusite, O. **Enargite, O. Goethite, O. Wolframite, M.**
- Non-metallic.—**Topaz, O.** Sillimanite, O. **Barite, O. Celestite, O. Staurolite, O. Amphiboles, M. Pyroxenes, M. Epidote, M.**
- Tabular Habit.—**Barite, O. Celestite, O. Calamine** (U. in radiating groups or crusts), O.
- Typical Monoclinic Habit.—**Orthoclase. Pyroxene. Amphibole. Titanite. Gypsum. Microcline, Tric.** Pseudo-monoclinic.
- Triclinic Habit.—Axinite. Chalcanthite.

GENERAL TABLE, III

FOR THE DETERMINATION OF MINERALS BY MEANS OF BLOWPIPE REACTIONS, SIMPLE CHEMICAL AND PHYSICAL EXAMINATION

Key

Division I. The mineral yields a **black** or **dark-colored** or **metallic streak** (metallic or submetallic luster).

SUBDIVISION A. The mineral gives a **sublimate** when heated **alone** on charcoal B.B.

Section a. Gives a sublimate of **arsenic oxide** (see p. 25).......... 105

Section b. Gives a sublimate of **antimony oxide** (see p. 23)........ 107

Section c. Gives a sublimate of **antimony** oxide and one of **lead** or **bismuth** oxide (see pp. 23, 44 and 29; confirm Sb, by test, 4, p. 24).................................... 108

Section d. Gives a sublimate of **lead** or **bismuth** oxide (see 1, 44 and 1, p. 29....................................... 109

Section e. Gives a sublimate of **zinc, tin,** or **molybdenum** oxide (see pp. 75, 69, and 49)........................... 110

Section f. Gives a sublimate of **tellurium oxide** (see 4, p. 68)...... 110

Section g. Gives a sublimate of **selenium** oxide (see p. 57)....... 111

SUBDIVISION B. The mineral **fuses** in the forceps or on charcoal B.B. but gives **no sublimate** 111

SUBDIVISION C. The mineral is **infusible** in the forceps or on charcoal B.B. and yields **no sublimate**....................... 114

Division II. The mineral yields a **white** or **light-colored streak** (non-metallic luster).

SUBDIVISION A. The minerals are **soluble** in **water** (have a **saline bitter** or **astringent** taste)............................ 119

SUBDIVISION B. Heated intensely **alone** in the C.T. **or** on charcoal (and sometimes by both methods) the mineral is partially or wholly **volatile**, or yields a sublimate **other** than **water; most of them fuse.**

Section a. Readily and completely volatile..................... 120

Section b. Yield a sublimate of **arsenic** oxide.................. 121

Sections c, d, e. Yield a sublimate of **lead** (*c*), **bismuth** (*d*), **antimony** (*e*) oxide............................ 122–3

Section f, g. Yield a **sublimate of zinc** (*f*), or **molybdenum** (*g*) oxide... 124

Section h. Fuse easily and yield a silver globule................. 124

SUBDIVISION C. The mineral **fuses**, B.B. but is **non-volatile** and yields **no sublimate** (except sometimes water) either in the C.T. or on charcoal.

Section a. The mineral turns, or remains, **black** on fusion B.B. and when cold is **attracted** by the magnet 125

Section b. After **fusion** B.B. the mineral yields an **alkaline** reaction on moistened turmeric or litmus paper [1] 128

SUBDIVISION D. The mineral **fuses** in the forceps B.B. but **does not react** as under A, B and C.

Section a. The mineral fuses to a **colorless glass** 129

Section b. The mineral fuses in the forceps to a **white glass, enamel** or **slag** [2] 132

Section c. The mineral fuses to colored or **black glass, enamel** or slag [2] 137

SUBDIVISION E. The mineral is **infusible** alone, B.B.

Section a. The mineral is **white**, or becomes so upon ignition B.B. The powder moistened with cobalt nitrate solution and then **intensely** ignited in charcoal B.B. assumes a fine **blue color** 143

Section b, etc. Minerals **not previously** included 146

APPENDIX TO KEY, TABLE III

When heated B.B. the mineral burns and may give an empyreumatic order—**carbon** and **hydrocarbons**. In some cases heated in the C.T. gases, tars and pitchy materials are sublimed.

Black or brownish-black, brittle	Coals
Black or brownish, of tar-like consistency	Bitumens
Yellowish to brownish, waxy	Natural waxes
Yellowish to brownish, brittle	Ambers

For description and details regarding these mineral substances see Dana's "System of Mineralogy," pp. 996–1024.

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[1] The absence of calcite (see test B. 1, p. 35) should be assured, as small amounts are very often present with other minerals and will give the alkaline **reaction.**

[2] See general remarks, p. 94, and note that slight impurities may cause the mineral to fuse white or colored, whereas if pure, it would fall in either *Section a* or *b*, and it may be necessary to look for it under these sections also.

Division 1. Minerals yielding a **black or dark colored or metallic** *streak*. (Metallic or submetallic luster.)

Subdivision A. The mineral yields a **sublimate** when heated alone B.B. on charcoal.

Section a. The mineral yields a **white, very volatile sublimate of arsenic trioxide** (p. 25). A garlic-like odor is often obtained. Rarely a sublimate of antimony or lead oxides may be obtained.

The color of the mineral is a dark gray or black. Hardness about 3 or 4.	Wholly volatile B.B.	*Native Arsenic.* U. Botryoidal. H = 2.5.
	Contain **copper** and **sulphur.** The nitric acid solution is rendered deep blue by the addition of ammonia.	**Enargite,** Cu$_3$AsS$_4$. O. Cleavage good. Color black. Tennantite, Cu$_8$As$_2$S$_7$. I. U. mass. May contain antimony. See Tetrahedrite below. The streak may be reddish. Pearceite, $9(Ag,Cu)_2S \cdot As_2S_3$. R. Silver test. For a few very rare minerals which fall here, see B. & P., p. 246.
	Contain **lead** and **sulphur.** Give a sublimate of lead oxide which comes later, and inside that of the arsenic.	For a few very rare minerals which fall here, see B. & P., p. 246.

Continued on next page.

Color pale copper-red.		NICCOLITE, $NiAs$. U. massive. Hardness 5 to 5.5.
The Color is Silver or Tin-white, Steel or Lead-gray, Hardness 5 to 6.	Wholly volatile B.B.	Native Arsenic, As. O. U. Botryoidal.
	Contain **Cobalt** (tests p. 37). In this group small amounts of Fe and Ni may be isom. with Co.	**Smaltite**, $CoAs_2$. I. **Cobaltite**, $CoAsS$. I. } Pyritohedral type of crystals. Glaucodot $(Co,Fe)AsS$. O. For other rare species which fall here, see B. & P., p. 246.
	Contain **Nickel** (tests p. 50). In this group small amounts of Co and Fe may be isom. w. Ni.	Chloanthite, $NiAs_2$. I. Gersdorffite, $NiAsS$. I. For other rare species which fall here, see B. & P., p. 247.
	Contain **Iron.** Fuse to strongly magnetic globules.	ARSENOPYRITE, $FeAsS$. O. clv. prism. Crystals common. Also massive. Löllingite, $FeAs_2$. Leucopyrite, Fe_3As_4. } Very rare.
	Contain **Platinum.**	Sperrylite, $PtAs_2$. I. Very rare.
	Contain **Copper.** The minerals are very rare.	Domeykite, Algodonite, Whitneyite, Mohawkite. { Copper arsenides. Mohawkite contains Co and Ni. Some of these are mixtures. For other species, see B. & P., p. 246.

I—A. *Section b.* The mineral **fuses with great ease** (1–1.5), and yields a **dense white** coating of **oxide of antimony** on charcoal (see 2, p. 23, confirm by 4, p. 24), but no **yellow sublimate** of **lead or bismuth oxide.** If doubtful as to the presence of latter, test for lead and bismuth, test 2 or 3, pp. 29, 30, and 3 or 4, pp. 45, 46.

Small amounts of arsenic may be present (isom. w. Sb) so that a slight garlic odor may be noted.

Sulphur is *present* in most of the minerals of this section.

Decomposed with conc. HNO_3, they yield a white residue (p. 24). For the most part they are quite soft.

Completely volatile. Color tin-white or lead-gray.	STIBNITE, Sb_2S_3. O. U. prism, columnar, bladed, rarely gran. *Clv.* pinc. perf. Marks paper. Native Antimony, Sb. R.
React for **silver.** Color dark red.	**Pyrargyrite,** Ag_3SbS_3. R. (Ruby silver in part.)
React for **Silver.** Color gray to black, except dyscrasite, which is silver-white.	Stephanite, $5Ag_2S.Sb_2S_3$. $\left.\begin{array}{l}\text{Miargyrite, } Ag_2S.Sb_2S_3.\\ \text{Polyargyrite, } 12Ag_2S.Sb_2S_3.\\ \text{Dyscrasite, } Ag_3Sb\ ?.\end{array}\right\}$ Rare.
React for **copper** and **silver.** Color gray to black.	Freibergite, $4(Cu,Ag)_2S.Sb_2S_3$. I. Polybasite, $9(Ag_2,Cu)_2S.Sb_2S_3$. R.
React for **copper,** color gray to black.	TETRAHEDRITE, Essentially $4Cu_2S.Sb_2S_3$. I. Tetrahedral crystals, U. massive. See also B. & P., p. 250.
React for **Iron** and **Nickel.**	For very rare species, see B. & P., p. 250.

I—A. *Section c.* The minerals **fuse with great ease** (1–1.5) and yield a **dense white coating of oxide of antimony** on charcoal B.B. (2, p. 23), and also a **yellow coating of lead oxide** (1, p. 44), rarely of bismuth (1, p. 29), or a white one of tin (3, p. 69), nearer the assay.

All of the minerals react for sulphur (test 2, p. 65).

A little arsenic may be present (isom. w. Sb) so that a slight garlic odor may be noticed.

Confirmatory test for Pb (3, p. 45), for Bi (2, p. 29).

The minerals are **black,** or some shade of **gray,** soft (H = 2–3.5) and of high density (Sp. G. = 5–6.5).

Contain **Lead, Antimony and Sulphur.**	**Jamesonite** (Feather ore), essentially $2PbS.\ Sb_2S_3$. U. has a finely fibrous structure. A number of *very rare* minerals, containing PbS and Sb_2S_3 in varying proportions, and distinguished by differences in physical properties fall here, see B. & P., p. 249.
Contains **Copper.**	**Bournonite,** $2PbS.Cu_2S.Sb_2S_3$. O.
Contains **Bismuth.**	See Brush and Penfield, p. 250.
Contain **Silver.**	For several rare species, see B. & P., p. 249.
Contain **Tin.** After long heating in O.F. leave a white non-volatile oxide (1, p. 69). Fused with char., and Na_2CO_3, give globules of tin.	Cylindrite, Franckeite, $PbS.SnS_2.FeS.Sb_2S_2$, in varying proportions. Very rare.

I—A. *Section d.* The mineral **fuses** and **yields a yellowish** *coating of* **lead or bismuth oxide.** (Confirm by tests, 2, p. 29 and 2 or 3, pp. 29–30.) The minerals with two exceptions are sulphides.

Contain **lead, but no bismuth.**	Native Lead, I. GALENITE (galena), PbS. I. In simple Isom. crystals, also coarse to fine granular. Clv. cubical perf. Sp. G. 7.6 H = 2.5–2.7.
Contain bismuth, but **no lead, copper nor silver.**	Native Bismuth, Bi. R. Clv. basal and rhomb. perf. Bismuthinite, Bi_2S_3. O. bladed or prismatic habit. Clv. pinc. perf.
Contain **bismuth and copper** or **silver,** but no **lead.**	The minerals are very rare. See B. & P., p. 251.
Contain both **lead and bismuth.**	The minerals are all very rare. See B. & P., p. 251.
Small amount of Cu and Ag may be isom. with Pb; also Sb iso. with Bi. (Cylindrite and Franckeite, 1—A, Section *c*, give a poor Sb test and might fall here.)	The minerals are all very rare. See B. & P., p. 251.

Some tellurium minerals, containing antimony may fall here also. See beyond, 1—A., *f*, p. 110.

I—A. *Section e.* The mineral yields a **sublimate of zinc** (1, p. 75), **tin** (1, p. 69), or **molybdenum** (1, p. 49), **oxide.**

Reacts for **zinc.** H_2S with HCl.	SPHALERITE (Zn,Fe)S. I. perf. Clv. in six directions (dodecahedral). Color black or brown. Streak, brown. H = 3. Infusible or nearly so. U. granular.
Contains **molybdenum.**	MOLYBDENITE MoS_2. R. Color bluish-gray; streak same when heavy. Foliated, very soft (H = 1). Clv. basal, perf. Resembles graphite.
Contains **tin.** B.B. in R.F. becomes magnetic. Reacts for copper.	Stannite, $Cu_2S.FeS.SnS_2$. Color steel-gray with yellowish tarnish. U. massive.

I—A. *Section f.* The mineral **fuses very easily** (1–1.5). Yields a **white sublimate** of *Tellurium oxide* B.B. on charcoal, and U. a pale bluish-green flame (4, p. 68. Confirm by test 1 or 3, p. 68). All the minerals of this group are of rare occurrence.

Wholly volatile B.B.	Native Tellurium, Te. R. Clv. prism. perf. Coloradoite, HgTe.
Contain **Bismuth.**	Tetradymite, Bi_2Te_3 to $2Bi_2Te_3.Bi_2S_3$. Clv. basal perf. See also B. & P., p. 248 for very rare minerals.
Contain **Lead.**	See B. & P., p. 248.

I—A. *Section f.*—Continued.

Contain **silver** or **gold**. U. both together. Ag. isom. with Au.	Hessite, Ag_2Te. Lead or silver-gray. U. massive. Somewhat sectile. H = 2.5–3. Petzite $(Ag,Au)_2Te$. Gray to black. Fine granular to compact. H = 2.5–3. Sylvanite $(Au,Ag)Te_2$. M. Clv. Pinc. (010) perf. Steel-gray to silver-white, inclining to yellow. H = 1.5–2. Krennerite $(Au,Ag)Te_2$. Prismatic, striated. Silver-white to brass-yellow. Calaverite, $AuTe_2$. Silver-white to yellow. Brittle. H = 2.5.
Contains **nickel** or **copper**.	Very rare minerals. See B. & P., p. 248.

I—A. *Section g.* The mineral yields a coating of **Selenium** oxide, p. 57. Gives a blue flame coloration and a very disagreeable odor.

For these very rare minerals see Brush and Penfield, p. 247.

I. Subdivision B. The mineral **fuses** B.B., but **yields no coating.**

The color is red, purplish or bluish.	Color red. Yield a copper globule easily B.B. on char. Contain no S.	NATIVE COPPER, Cu. I. Malleable. CUPRITE, Cu_2O. I. Simple cryst. forms, also fibrous and massive. Brittle. H = 3.5–4.
	Reacts for copper and sulphur. Yield sulphur in the C.T.	BORNITE, Cu_5FeS_4. U. massive. Mag. B.B. in R.F. The freshly broken surface is reddish bronze. The old surface is purplish or blueish. Covellite, CuS. Tabular habit. Soft. H = 1.5–2. Color, purplish-blue.

Continued on next page.

I—A. *Section g.*—Continued.

The color is pale to deep yellow. All but gold fuse to magnetic globules (Fe, Ni, or Co) and react for sulphur.	Malleable, insoluble in any single acid.	GOLD, Au. I. Yellow (Electrum, Au,Ag, is light yellow).
	Hardness **greater then steel.** Burns, yielding SO_2. Abundant S in C.T.	PYRITE, FeS_2. I. Cryst. cubes, pyritohedrons, octahedrons. Also mass., granular. Light brass-yellow. MARCASITE, FeS_2. O. Cryst. and mass. Color U. paler yellow than pyrite.
	Hardness less than steel. Reacts for copper and iron and gives S in the C.T.	CHALCOPYRITE, $CuFeS_2$. T. Crystals tetrahedral in habit. Brass-yellow color. U. massive.
	Reacts for nickel (2, p. 50).	**Millerite,** NiS. (capillary pyrite). Prismatic to hair-like crystals, often in radiating groups. Pentlandite (Ni,Fe)S. U. massive. Yellowish-bronze color. Occurs with Pyrrhotite.
The color is that of bronze. Fuse to *magnetic globules* in the R.F. React for sulphur.	Contains only **Iron** and sulphur. U. mag. without heating.	PYRRHOTITE, FeS+XS. U. massive. Brownish-bronze color. Gives a slight sublimate of S. in C.T.
	Reacts for nickel (2, p. 50).	Pentlandite (Ni,Fe)S. See above.
	Contains copper and iron.	**Bornite,** see above.
	Contains silver and iron.	Sternbergite, $AgFe_2S_3$.

I—A. *Section g.*—Continued.

The color is silver-white, steel-gray, or gray. All but silver react for sulphur.	Fuses to a silver-white, malleable globule.	**Native Silver, Ag.** I. Malleable.
	Soft. After roasting gives a copper globule on char.	CHALCOCITE (Copper glance). Cu_2S. O. U. mass. Black tarnish. Almost *sectile.* H=2.5–3. Stromeyerite $(Cu,Ag)_2S$. H=2.5–3.
	Contain cobalt or nickel, and often iron.	Linnaeite, $(Co,Ni)_3S_4$. I. H=5–5.5 Polydymite, Ni_4S_5. For other species, see B. & P., p. 252.
The color is **black** *or* **brownish-black.**	**Very soft. Sectile,** vis., cut like lead. Fuse easily. Yield a bright silver globule on char.	**Argentite** (Silver glance), Ag_2S. I. **Acanthite**, Ag_2S. O.
	Yields a **copper globule** on char.	CHALCOCITE, Cu_2S. (Copper glance). O. U. massive. Almost sectile. Fresh surface is dark gray. H=2.5–3. Tenorite (melaconite), CuO. U. massive. Often impure.
	The streak of these minerals is quite dark (grayish or greenish), although not metallic. Fuse with **intumescence.** Ilvaite yields a strongly magnetite black globule B.B. in R.F. Allanite U., and Tourmaline sometimes, yields a mag. globule.	TOURMALINE, a borosilicate of Al, Fe, etc. R. U. prism. and striated vertically; hex. or triangular section. Test for boron. 1, p. 31. Ilvaite. Orthosilicate of Ca and Fe. Allanite. Orthosilicate of Ca, Fe, Al, and the rare earths Ce, La, and Di. Test for earths, p. 55. Riebeckite, a soda-iron amphibole. Clv. perf., prism. (∠ of 124°). Strong yellow flame. See also other iron rich amphiboles, p. 127.

Continued on next page.

I—A. *Section g.*—Continued.

The color is **black** *or* **brownish-black.**	Imparts to the Na_2CO_3 bead in O.F. a bluish-green color (manganese). Wolframite often decrepitates violently B.B.	**Wolframite,** (Fe,Mn)WO_4. M. Clv. pinc. perf. Black to brown, or reddish-brown streak. Sp. G. very high (=7). H=5–5.5. Test for W., 2, p. 71. Alabandite, MnS. Olive-green streak.
	Reacts for Tungsten, 2, p. 71.	Ferberite, $FeWO_4$. M.
	Diff. fusible.	See under Iron Oxides. Division 1, Subdiv. C.
	Diff. fusible. React for Niobium. 1, p. 51	See Columbite. I, Subdiv. C. Samarskite. Reacts for rare earths and Uranium. See pp. 59, 71.
	Ilmenite (see beyond, 1, *c.*) may fuse and show slight, or no magnetic properties.	

Division I. Minerals yielding a black or dark colored streak.

Subdivision C. The mineral is **infusible** in the forceps or on charcoal B.B., and yields no sublimate.

Metallic. Color gray. Easily scratched by steel. More or less malleable. Insoluble in any single acid.	**Platinum** and the platinum metals. Platinum may contain considerable iron and be somewhat attracted by a magnet. Iridosmine is rather brittle.
Black, **very soft,** readily marks paper	GRAPHITE, Hex. R. Clv. basal. perf. Scales or plates. Streak black or dark lead-gray in reflected light. PYROLUSITE, MnO_2, and a little H_2O. Prismatic, fibrous, radiate, also earthy. H=2. Test, 2, p. 48. H_2O in C.T.

Continued on next page.

I—C.—Continued.

<table>
<tr><td colspan="2">Strongly attracted by magnet without heating in R.F.</td><td>MAGNETITE, Fe_3O_4. I. Crystals U. octahedral. U. granular. H = 5.5–6.5. Streak black.
HEMATITE (see below), often contains enough magnetite to render it magnetic. Its streak is dark red.
Franklinite, a var. of magnetite, see next page.
TITANIC IRON (in part) $FeTiO_3$ with var. proportions of Fe_3O_4 and Fe_2O_3. H = 5.5–6.5. Streak Black.
U. granular. Titanium test, 1, p. 69.
$\left.\begin{array}{l}\text{Magnesioferrite, } MgFe_2O_4.\\ \text{Native Iron, Fe and often Ni.}\\ \quad\text{Meteoric mostly.}\end{array}\right\}$ Rare.
Awaruite, $FeNi_2$.</td></tr>
<tr><td>After heating intensely in the forceps B.B. the cold fragment is attracted by the magnet.</td><td>The streak is red.</td><td>HEMATITE (Specularite) Fe_2O_3. Rhomb. Parting ‖ to R. and base. Crystals commonly tabular, micaceous; also granular. Color steel-gray to black; brilliant in luster. Streak dark red. H = 5.5–6.5.
The mineral also occurs in reniform, botryoidal masses, with splintery or fibrous structure. Also earthy. The hardness is less than for the crystals, and the streak is a brighter red.
Turgite, Fe_2O_3 + Water. U. fibrous or splintery, botryoidal, earthy. Streak bright red. H_2O in C.T.
ILMENITE. See below, may give a dark reddish streak.</td></tr>
</table>

Continued on next page.

I—C.—Continued.

After heating intensely in the forceps B.B. the cold fragment is **attracted** by the magnet.	The **streak** is some shade of **brown.**	**LIMONITE** (Brown Hematite, Bog Iron ore), $2Fe_2O_3.3H_2O\pm$. In botryoidal, reniform or stalactitic forms and then with finely fibrous structure. Also compact, earthy and soft. Color brown to almost black, for hard vars. Yellowish-brown when soft. **Streak yellowish** to **ochre-brown.** $H=5$–5.5 or less. Abund. H_2O in C.T. **Goethite,** $Fe_2O_3.H_2O$. O. Clv. $\parallel$ to 010, perf. U. with radiate, prismatic or fibrous structure. Yellowish, reddish to blackish-brown. **Streak yellowish** to **ochre-brown.** H_2O in C.T. **Franklinite,** $(Fe,Mn,Zn)O.(Fe,Mn)_2O_3$. I. Octahedral. U. granular. Color black. Streak brown. $H=6$. Tests, Mn, 1, p. 47. Zn, 2, p. 75.
	The **streak** is **black** or nearly so.	Psilomelane (see below), may become magnetic B.B. Its streak is nearly black. **ILMENITE** (Menaccanite) $FeTiO_3$ (often admixed with magnetite and hematite). Rhomb. Crystals U. tabular. Commonly granular. Color black. $H=5$–6. Streak black or slightly brown or reddish. Titanium test, 1, p. 69. **CHROMITE,** see below, may become magnetic B.B.

Continued on next page.

I—C.—Continued.

After heating intensely in the forceps B.B. the cold fragment does not become magnetic.	React for **Manganese** in the **soda bead** test 1, p. 47. Manganite and Hausmannite have brown streaks. The rest have black, or nearly black streaks.	**Manganite,** $Mn_2O_3.H_2O$. O. Prismatic, fibrous, often radiate. Clv. ‖ to 010. perf. Color black. Streak brown. H=4, H_2O in C.T. **Pyrolusite,** MnO_2+Water. Prismatic, fibrous, radiate, also earthy. **Very soft.** H=2. Test 2, p. 48. H_2O in C.T. **Columbite** $(Mn,Fe)(Nb,Ta)_2O_6$. O. Color iron-black, grayish or brownish-black. Streak black or brownish-black. H=6. Heavy. Sp. G. 5 to 7. Tests, Nb, 1, p. 51. Ta, p. 67. Tantalite, $(Mn,Fe)Ta_2O_6$. O. Properties similar to Columbite, except Sp. G.=7+, and little or no Nb is present. **Psilomelane,** $MnO_2.MnO$ with K_2O, BaO, Fe_2O_3 and H_2O. Noncryst. massive, botryoidal, stalactitic. Color black to steel-gray. Streak black to brownish-black. H=5–6. Ba, 3, p. 28. H_2O in C.T. Hausmannite, Mn_2MnO_4. T Octahedral, also granular. Braunite, $3Mn_2O_3.MnSiO_3$. T. Octahedral. Also massive. Polianite, MnO_2. T. U. cryst. Color light steel to iron-gray. H=6–6.5.
	In the borax bead reacts for Chromium, 1, p. 36.	**CHROMITE,** $FeCr_2O_4$ (may contain Mg and Al). I. Octahedral. U. granular. Color black. Streak, brown. H=5 up.

Continued on next page.

I—C.—Continued.

After heating intensely in the forceps B.B. the cold fragment does not become magnetic.	Very high Sp. G. In the Salt of Phosphorus bead reacts for Uranium, 1, p. 71.	Uraninite (Pitch Blende, Cleveite) Ur . Pb . Ra . N . He and various other elements. Color, grayish, greenish, brownish, velvet-black. Streak variable, but dark. Very high Sp. G. (=9). H=5.5. Tests, U. 1 or 2, p. 71. Gives a slight coating of lead oxide with soda B.B. on char.
	Reacts for Ti (1, p. 69) or for Nb (1, p. 51).	Nigrine var. of Rutile, TiO_2, containing Iron oxide. Fergusonite, Nb.Ta Y.Ce, etc. Color, black. Streak, brown. Becomes yellow B.B. Ta, p. 67. Rare earths, p. 55. High Sp. G.

Division II. The **streak** or **very fine powder** is **white** or **light colored.** (Minerals of non-metallic luster.)

Subdivision A. The minerals are **soluble in water.** They have for the most part a *salty*, *bitter*, or *astringent taste;* for the most part are very easily fusible. With a few exceptions the minerals of this group are of rare occurrence and are generally found in dry or desert localities.

There are also quite a large number of rare species which fall here that are not listed. For these see Brush and Penfield's "Determinative Mineralogy," p. 271.

Color green or blue.	React for **Sulphuric** acid. Acid H_2O in C.T.	Chalcanthite, $CuSO_4.5H_2O$. Tri. Melanterite, $FeSO_4.7H_2O$. M.
After intense ignition B.B., they yield an alkaline reaction when placed on moistened test paper. f, p. 8.	**Chlorides.** The HNO_3 solution gives a white ppt. with $AgNO_3$.	HALITE (Common salt), NaCl. I. Clv., cubical perf. Intense yellow flame color. **Sylvite,** KCl. I. Violet flame color. Clv. cubical perf. Carnallite, $MgCl_2.KCl.6H_2O$. Violet flame color. Kainite, $MgSO_4.KCl.3H_2O$.
	Carbonates. Effervesce with acids. Intense yellow flame color.	Natron, $Na_2CO_3.10H_2O$. Trona, $Na_2CO_3.HNaCO_3.2H_2O$.
	Sulphates. The solution, made acid with HCl gives a dense white ppt. with $BaCl_2$.	Thenardite, Na_2SO_4. Intense yellow flame color. **Kalinite,** $KAl(SO_4)_2.12H_2O$. I. Swells B.B. and gives a violet flame color. **Epsomite,** $MgSO_4.7H_2O$. Mirabilite (Glauber salt). $Na_2SO_4.10H_2O_4$. Alunogen, $Al_2(SO_4)_2.18H_2O$.

Continued on next page.

II—A.—Continued.

After intense ignition B.B., they yield an **alkaline reaction** when placed on moistened test paper. f, p. 8.	**Nitrates.** Heated in a bulb tube with $HKSO_4$ red vapors of NO_2 are evolved.	**Soda Niter,** $NaNO_3$. Rhomb. Intense yellow flame color. **Niter,** KNO_3. O. Violet flame color.
	Borates. Boracic acid test, 2, p. 31.	Sassolite $B(OH)_3$. U. in scales. White. Very soft. $H=1$. Gives a yellow-green flame color. **Borax,** $Na_2B_4O_7.10H_2O$. M. Heated on a loop of plat. wire, swells and fuses to clear glass, yielding intense yellow flame color.

Becomes black and magnetic B.B. H_2SO_4 test.	Copiapite, $Fe_2(Fe.OH)_2(SO_4)_5.17H_2O$. Acid H_2O in C.T. Color sulphur-yellow.
B.B. in the R.F. gives a coating of ZnO on charcoal. Infusible.	Goslarite, $ZnSO_4.7H_2O$. U. fibrous.

Division II. SUBDIVISION B. Heated alone intensely in the C.T. or on charcoal (sometimes by both methods), the mineral is **partially** or **wholly volatile,** or **yields** a **sublimate** (other than water).

Most of them fuse.

Section a.

Section a. **Readily** and **completely volatile** when pure. Cinnabar is commonly impure and often leaves a considerable residue.	CINNABAR, HgS. R. Color and streak **vermilion-red.** U. massive granular. C.T. test, 1, p. 48.

Continued on next page.

II—B. *Section a.*—Continued.

Section a. **Readily and completely volatile** when pure.	**Realgar**, As_2S_2. Color and streak **aurora to orange-red.** Very soft. Gives a dark red to yellow sublimate on C.T. Fades on cooling. **Orpiment**, As_2S_3. U. foliated. Clv. pinc. perf. Very soft. Color and streak **lemon-yellow.** Tests as for Realgar, above. SULPHUR, S. O. Often in fine crystals, also massive. Brittle and soft. Color U. **pale yellow.** Burns with blue flame. Odor of SO_2. Kermesite, Sb_2S_2O. U. needlelike, tufted. Color red. Sectile. H = 1–1.5. Turns black when hot. Arsenolite. I. } Claudetite. M. } As_2O_3. U. white. Senarmontite. I. } Valentinite. O. } Sb_2O_3. U. white.

A number of other very rare minerals fall here, viz., Lorandite, $TlAsS_2$ (green flame); Sal Ammoniac, NH_4Cl; Mascagnite $(NH_4)_2SO_4$; Calomel, HgCl; Terlinguaite, Hg_2ClO; Egglestonite, Hg_4Cl_2O(Hg test, 1, p. 48); Cotunnite, $PbCl_2$. See B. & P., p. 258, and Dana.

II—B. *Section b.*

Section b. Are not wholly volatile B.B. Yield a sublimate of arsenic trioxide on charcoal. U. give a garlic odor.	Become magnetic B.B. in the R.F. Soluble in HCl.	**Erythrite** (Cobalt Bloom). $Co_3(AsO_4)_2.8H_2O$. Red or crimson color. U. fibrous or earthy. **Annabergite** (Nickel Bloom). $Ni_3(AsO_4)_2.8H_2O$. Color apple-green. U. fibrous or earthy. Scorodite, $FeAsO_4.2H_2O$. O. Color green or brown. U. cryst. Pharmacosiderite, $Fe(Fe.OH)_3(AsO_4)_3.6H_2O$. I. U. cryst. in cubes. Color green, yellow, brown, red.

Continued on next page.

II—B. *Section b.*—Continued.

Section b. Are not wholly volatile B.B. Yield a sublimate of arsenic oxide on charcoal. U. give a garlic odor.	Become magnetic B.B. in the R.F. Soluble in HCl.	A few **very rare** minerals fall here. See B. & P., p. 267.
		Mimetite, $Pb_4(PbCl)(AsO_4)_3$. H. U. in rounded crystals. Color U. yellow or orange-brown. Lead globules w: soda. $PbCl_2$ sublimate in C.T. Endlichite—like Mimetite, but contains Vanadium (1, p. 72).
	Do not become magnetic B.B. in R.F.	**Olivenite**, $Cu_2(OH)AsO_4$. O. U. prism. Color blackish to olive-green or brown. Chalcophyllite, $7CuO.As_2O_5.14H_2O$. R. Color green. Cryst. tabular, foliated drusy. H = 2. Conichalcite, a hydrous arsenate of Cu and Ca. Color yellowish-green to emerald-green. Reniform and massive.
		Proustite (Ruby silver), $3Ag_2S.As_2S_3$. H. Ruby-red color. Silver glob. after roasting.

A considerable number of very rare species fall here. For their identification see Brush and Penfield's "Determinative Mineralogy," pp. 259, 260, 262, 264, 265.

II—B. *Sections c, d, e.*

Section c. When strongly heated B.B. in the R.F., the minerals fuse easily and yield a coating of lead oxide. Confirm by test, 2, p. 45.	B.B. yields a white, volatile coating of lead chloride (p. 79). Pyromorphite, see below U. yields a slight coating of lead chloride.	Phosgenite, $(PbCl)_2CO_3$. T. U. cryst. Colorless or white. Several rare species fall here, see B. & P., p. 261.

Continued on next page.

II—B. *Sections c, d, e.*—Continued.

Section c. When strongly heated B.B. in the R.F., the minerals fuse easily and yield a coating of lead oxide. Confirm by test, 2, p. 45.	These minerals are all soft and have **high specific gravities.**	CERUSSITE, $PbCO_3$. O. U. cryst. white and lustrous. Brittle. Yields a globule of lead readily without fluxes. Effervesces readily with dilute HNO_3. ANGLESITE, $PbSO_4$. O. Cryst. and massive. Insol. in acids. S. test, 2, p. 67. PYROMORPHITE, $Pb_4(PbCl)(PO_4)_3$. H. U. cryst. in hex. prisms. Color U. green or brown. Fuses to cryst. globule. PbCl in C.T. **Vanadinite,** $Pb_4(PbCl)(VO_4)_3$. H. U. cryst. in hex. prisms. Color red, yellow, brown. Vanadium test, 1, p. 72. WULFENITE, $PbMO_4$. T. U. cryst. tables or plates. Color yellow, orange, brownish. Mo. test, 2, p. 49. Crocoite, $PbCrO_4$. M. U. cryst. Color bright red. Cr. test, 1, p. 36. Descloizite, a hydrous vanadate of lead and zinc. Color red, brown to black. May react for Cu.

(A considerable number of rare species also fall here. See Brush and Penfield, pp. 259, 260, 261.)

Section d. B.B. yields a coating of bismuth oxide; confirm by 2, p. 29.

Bismutite, $BiO(Bi.2OH)CO_3$ (white, green, yellow), and a few other species, all very rare, fall here. See Brush and Penfield, p. 262.

Section e. Several very rare species containing antimony and yielding an antimony oxide sublimate on char. fall here. See Brush and Penfield, p. 263.

II—B. *Sections f, g, h.*

Section f. The following zinc minerals while infusible or fusible with difficulty, yield on strong heating B.B. in the R.F. a yellowish coating of ZnO on charcoal 1, p. 74. Calamine and Willemite fused with soda and char. give the ZnO coating more satisfactorily than when heated alone.	SPHALERITE (Blend), ZnS. I. Clv. in six directions duodecahedral perf. U. cryst. granular. Color yellow, red to brown. Streak yellow to light brown. Gives H_2S w. effervescence in HCl. SMITHSONITE, $ZnCO_3$. R. U. botryoidal. CO_2 in acids. Various colors. CALAMINE, $(ZnOH)_2SiO_3$. O. Cryst., prism., radiated, encrusted, or botryoidal in structure. Yields gelatinous silica with acids. H_2O in C.T. Willemite, Zn_2SiO_4. R. U. granular or mass. cryst. Color green, yellowish green, or brown. Yields gelatinous silica with acids, U. occurs with franklinite. Zincite, $(Zn,Mn)O$. Color U. dark red. Streak yellow.
Section g. Yield a sublimate of Molybdenum oxide, 1, p. 49.	Molybdic Ochre, $Fe_2O_3.3MoO_3.7H_2O$. Yellow. Massive. Molybdite, MoO_3. In fibrous, tufted also powdery incrustations, also massive. Color yellow. Very soft.
Section h. Easily fusible—partially volatile and leave a globule of silver B.B. on char. Cut like wax with a knife (Sectile). For tests for Cl, I. and Br. see 1, p. 35, and pp. 31, 42.	Cerargyrite, $AgCl$. I. Cubical crystals; also wax-like masses. Color brown, gray to greenish. Bromyrite, $AgBr$. I. Iodyrite, AgI. I. Isom. mixtures of $AgCl$, $AgBr$, and AgI occur. See species Embolite, Idobromite. The color of these varies from yellow to yellow-green.

Division II. SUBDIVISION C. The mineral **fuses B.B.** but is **non-volatile** and yields **no sublimate** either in the C.T. (except sometimes water) or on charcoal.

Section a. On fusion in the R.F. the mineral *blackens*, or remains black, and when cold is **attracted by a magnet** (iron).

Difficultly fusible. Effervesce in warm dilute HCl or HNO_3. U. cryst. and show a cleav. in three directions. (Rhomb.)	SIDERITE, $FeCO_3$. R. Color light brown, becomes dark brown on alteration. H = 3.5–4. **Ankerite** $(Ca)(Mg,Fe)(CO_3)_2$. R. Color gray, light brown. RHODOCHROSITE, $(Mn,Fe)CO_3$. R. Color U. pink or red, rarely brown. H = 3.5–4.5. Mn, test 1, p. 47.
Micaceous. Clv. perf. basal. Yields thin leaves or flakes. Black or greenish black in color.	**Lepidomelane** (Iron mica). Complex silicate of Fe and Al. Yields gelatinous silica with acids.
Elongate or bladed crystals, often with radiate grouping. Color bronze or yellow.	Astrophyllite. O. Clv. pinc. perf. Complex silicate containing Na, K, Fe, and Ti. Decomposed with separation of SiO_2 by acids.
Soluble in HCl yielding **gelatinous** silica upon evaporation (1, p. 57).	ANDRADITE (Garnet in part), $Ca_3Fe_2(SiO_4)_3$.I. U. cryst. dodecahedral, also granular. U. brown or greenish-brown. Gelatinizes imperfectly. **Allanite,** complex silicate containing Fe, Al, Ca and the Rare Earths. Color brown to pitch-black. Test for earths, p. 55. Swells and froths during fusion.

Continued on next page.

II—C. *Section a.*—Continued.

Soluble in HCl yielding **gelatinous silica** upon evaporation (1, p. 57).		Ilvaite, silicate of Ca and Fe. Color black. *Fayalite*, Fe_2SiO_4. O. Color yellowish to dark yellowish-green. Luster resinous. Stilpnomelane, a complex hydrous silicate of iron, magnesium and aluminum. Minute plates, fibrous, radiated. Color green to black, bronzy. Thuringite Chamosite Essentially hydrous silicates of iron and aluminium. Compact aggregation of minute scales or oölites. Color olive-green to almost black. For other species see B. & P., p. 269.
Soluble in acids but do not yield gelatinous silica.	**Phosphates**, test 2, p. 52. (A considerable number of other rare phosphates fall here. See Brush–Penfield, p. 268.)	**Vivianite**, $Fe_3(PO_4)_2.8H_2O$. M. U. prism. Clv. pinc. perf. Color blue, bluish green, colorless. Triphylite, $Li(Fe,Mn)PO_4$. U. mass. Color light blue, green, or gray. Crimson flame (Li). Triplite, contains Fe, Mn, and F. U. mass. Color chestnut to blackish brown. Childrenite, contains Fe, Mn, Al. O. U. cryst. Color yellowish-brown to brownish-black.
	Sulphates, test 1, p. 66. In the C.T. give acid water. (Some only on intense ignition.)	**Jarosite**, $K(Fe.2OH)_3(SO_4)_2$. H. U. cryst. Color ochre-yellow to clove-brown. (A large number of rare sulphates fall here. See Brush–Penfield, pp. 266–7.

Continued on next page.

II—C. *Section a.*—Continued.

Insoluble or nearly so in hydrochloric or nitric acid. The minerals of this group are for the most part silicates. Test 3, p. 58.	**Tungstate,** 2, p. 69. Very high Sp. G.	WOLFRAMITE, $(Fe,Mn)WO_4$. M. Clv. pinc. perf. Streak and color dark reddish-brown to black.
	B.B. fuses with marked **intumescence.** Arfedsonite, Riebeckite, and crocidolite contain much Na and Fe and give a strong yellow flame color.	EPIDOTE, $Ca_2Al(OH)(AlFe)_2(SiO_4)_3$. M. Color U. yellowish-green. U. cryst. prism. Clv. basal perf. Ceases to intumesce after a little heating. **Arfvedsonite,** **Riebeckite,** Color black. U. cryst. prism. Clv. prism. perf. **Crocidolite,** color bluish, fibrous. See also other vars. of hornblende. Essentially $NaFe(Si_2O_6)$ **TOURMALINE,** see below.
	Fuse **quietly** B.B. with little or no intumesence. (See also certain black varieties of Augite and Hornblende which may contain sufficient Fe to render them magnetic B.B. (Div. II, D–c.) See also difficultly fusible iron oxides. Div. I–C.)	TOURMALINE, A borosilicate of Al,Fe, etc. R. U. prism. and striated vertically; hex. or triangular section. Color black. Boron test 1, p. 31. ALMANDITE (garnet in part), $Fe_3Al_2(SiO_4)_3$. I. U. cryst. in duodecahedrons or trapezohedrons; also granular. Color dark red. **EPIDOTE,** see above. Aegerite, Acmite, $NaFeSi_2O_6$. M. U. in prism. crystals. Color U. green to dark green, rarely brownish. Yellow flame color.

Continued on next page.

II—C. *Section a.*—Continued.

Insoluble or nearly so in hydrochloric or nitric acid. The minerals of this group are for the most part silicates. Test 3, p. 58.		Glauconite, a hydrous silicate of iron and potassium. Loosely granular earthy, massive. Color, varying shades of green. K. test 1, p. 53. Some vars. are slightly soluble.
	Prismatic, fibrous, lamellar.	Anthophyllite, $(Mg,Fe)Si_2O_6$. Gray, green, brownish.

Division II. SUBDIVISION C. *Section b.* After fusion B.B. the fragment yields an **alkaline reaction** on moistened turmeric or reddened litmus paper. See f, p. 8.

Yellowish-red flame color; not distinctive. (Use Spectroscope).	GYPSUM (Selenite), $CaSO_4.2H_2O$. M. Cryst. fibrous, granular, mass. (Alabaster in part). Clv. pinc. perf. Crystals may be split easily into thin plates. U. white or pinkish. Crystals colorless. Sp. G. $=2.32$. Very soft. $H=2$. Soluble in dilute, hot HCl. Test 3, p. 33.
	ANHYDRITE, $CaSO_4$. O. U. mass. When cryst. Clv. in 3 directions at nearly rt. angles. U. white. Sol. in hot dilute HCl. $H=3–3.5$.
Strong yellow flame color. $F=1.5$. $H=2.5$.	**Cryolite,** Na_3AlF_6. M. Poor pseudo-cubic clv. F. test 1, p. 39. Gay-Lussite, $Na_2CO_3.CaCO_3.5H_2O$. M. U. cryst. Intense yellow flame color. Effervesces freely in dilute acids. H_2O in C.T.

Continued on next page.

II—C. *Section b.*—Continued.

Strong **yellowish-red** flame color. Fragments U. decrepitate B.B. (Use Spectroscope.)	FLUORITE (fluorspar), CaF_2. I. U. cryst. in cubes. Clv. octahedral (4 directions) perf. Color yellow, green, purple, also colorless. H=4. Sp. G. 3.18. F. test, 1, p. 39.
Bright **red** or **crimson** flame color. (Use Spectroscope.)	**Celestite,** $SrSO_4$. O. U. cryst. Clv. basal perf. and prism. Colorless or white. H=3.5 Sp. G.=3.9. Diff. sol. Sr test, 3, p. 64.
Yellow-green flame color. High specific gravity. (Use Spectroscope.)	BARITE, $BaSO_4$. O. Cryst. U. tabular; granular, also compact. Clv. basal perf. and prism. U. white. H=3.3–5. Sp. G.=4.5. Nearly insol. in hot HCl. Ba test, 3, p. 28. **Witherite,** $BaCO_3$. O. (Pseudo-hex.) U. cryst. mass. U. white. H=3.5. Sp. G.=3.9. Effervesces readily with dilute HNO_3.

For other species, see Brush and Penfield, p. 274.

Division II. SUBDIVISION D. The mineral fuses in the forceps B.B. but does not become magnetic, volatilize, yield a coating on charcoal, nor give an alkaline reaction.

Section a. The mineral fuses to a **colorless** glass. A number of species fuse to a clear glass which superficially appears white, owing to the presence of bubbles. For such see also under *Section b*, beyond.

Special reaction	Yields a red flame coloration.	**Lepidolite,** see beyond. **Spodumene,** see beyond.
	Yields a yellowish-green flame coloration.	**Datolite,** see beyond. Danburite, see beyond.

Continued on next page.

II—D. *Section a.*—Continued.

Special reactions	Fuse with swelling, branching or intumescence.	**Lepidolite** **Spodumene** **Datolite** **Stilbite** See below.
Soluble in dilute HCl or HNO_3 and yield gelatinous silica upon evaporation, see 1, p. 57.	Yields a green flame color.	**Datolite,** $Ca(B.OH)SiO_4$. M. U. in white or colorless crystals of complex habit. H = 5 to 5.5. Fus. (= 2) with marked intumescence. H_2O in C.T. **Danburite,** $CaB_2Si_2O_8$. O. U. cryst. prism. H = 7. Rather insoluble.
	Yields yellow flame color.	NEPHELITE, $NaAlSiO_4$. U. crystalline, mass. H = 5.5–6. Greasy luster. Colorless, gray, white, pink. Whitened, altered portions yield H_2O in C.T. (Kaolin). U. assoc. with feldspar. **ANALCITE.** $NaAl(SiO_3)_2.H_2O$. I. U. cryst. in trapezohedrons. U. colorless or white. Yields rather poor jelly. **NATROLITE,** $Na_2Al_2Si_3O_{10}.2H_2O$. O. U. cryst. in slender prisms or needles. White. **Sodalite,** $Na_4(AlCl)Al_2(SiO_4)_3$. U. mass. Color deep blue. Cl. test.
Decomposed with the separation of non-gelatinous, powdery silica (see 2, p. 58).		LABRADORITE, $NaAlSi_3O_8.CaAl_2Si_2O_8$. Tri. Clv. perf. in two directions at right angles. One clv. face U. striated. Partially decomposed by acids.

Continued on next page.

II—D. *Section a.*—Continued.

Decomposed with the separation of non-gelatinous, powdery silica (see 2, p. 58.		**ANALCITE,** see above. U. gives a poor jelly. **Stilbite,** $H_4(Ca,Na_2)Al_2(SiO_3)_6.4H_2O$. U. cryst. in sheaf-like groups. Fuses with swelling and intumescence. H_2O in C.T.
Soluble in HCl but without separation of silica or gelatinization.		Ulexite, $NaCaB_5O_9.8H_2O$. White, silky fibers. Boron test, 2, p. 31.
Insoluble or nearly so in HCl and HNO_3.	B.B. gives a **red flame** coloration (the red is sometimes partly obscured by sodium).	**Spodumene,** $LiAlSi_2O_6$. M. U. cryst. as flat prisms often of large size. Tough, splintery prism. clv. H=6.5–7. B.B. U. throws out branches. **Lepidolite** (Lithia mica), silicate of Li and Al. Micaceous in habit. Clv. basal perf., yielding plates or flakes. Colorless, pink, lilac. Fuses with much intumescence. H=2.
	Green flame.	Danburite, see above.
	Possesses **two good cleavages at nearly right angles** to each other. One cleavage face commonly shows fine parallel **striations.**	ALBITE, $NaAlSi_3O_8$. Tri. Cryst. and U. of tabular habit. H=6. Contains no Ca and but little or no K. (Test, *b*, p. 54.) OLIGOCLASE, $3NaAlSi_3O_8.CaAl_2Si_2O_6$. Tri. Reacts for a little Ca but little or no K.
	Prismatic habit. Good cleavage at angle of about 125°.	TREMOLITE, $CaMg_3(SiO_3)_4$. M. Color white or gray. H=5 to 6. Test 4, p. 58.

Continued on next page.

II—D. *Section a.*—Continued.

Insoluble or nearly so in HCL and HNO_3.	Finely **fibrous** habit.	**Tremolite Asbestos.** See Tremolite above. White color.
	Monoclinic crystals. Prism angle about 87°; also granular.	DIOPSIDE, $CaMg(SiO_3)_2$. M. Color, white, gray, light green. H=5–6. Test 4, p. 58.
	Color bluish. Prismatic to almost fibrous struct.	**Glaucophane,** $Na_2Al_2Si_4O_{12}+(Mg,Fe)_4Si_4O_{12}$. M. Yellow flame color.
	Compact structure. Color white, gray, greenish.	Jadeite, $NaAlSi_2O_6$ (Jade in part). Yellow flame color.

II—D. *Section b.* The mineral fuses in the forceps B.B. to a **white, glass, enamel,** or **slag.**

See general remarks, p. 94, and note that slight impurities or variations in composition may cause the mineral to fuse white or colored, whereas, if pure it would fall in *Section a,* and it is well to compare the minerals there listed where any uncertainty exists.

Special reactions or structures.	Yields a **red flame** coloration.	Lepidolite, see Section a. Spodumene, see Section a. Amblygonite, see below. Petalite, see below.
	Yields a **greenish flame** coloration.	Boracite, see below. Colemanite, see below.
	Fuse with, swelling, branching, or intumescence.	Scolecite, Mesolite, Thomsonite, Laumontite, Spodumene, Chabazite, Stilbite, Heulandite, Apophyllite, Lepidolite, Cancrinite. For these, see below.
	Distinct micaceous structure.	Lepidolite Muscovite Margarite See beyond.

Continued on next page.

II—D. *Section b.*—Continued.

Dissolves with **effervescence** in dilute HCl or NHO_3 (warming may be necessary).		Cancrinite, $H_6(Na_2,Ca)_4(Al.NaCO_3)_2Al_6(SiO_4)_9$. U. mass. Color U. yellow. Swells and froths during fusion. Yields gelatinous silica. $H = 5.5–6$.
Decomposed by HCl with the **separation** of a bright yellow residue, Tungstic acid. Test 1, p. 70.		**Scheelite,** $CaWO_4$. T. Color white High Sp. G. = 6. $H = 4.5–5$.
Dissolve in dilute HCl or HNO_3 and yield gelatinous silica upon evaporation. (1, p. 57.) All are hard (5–6), except Laumonite ($H = 3–4$.)	Color usually blue.	Lazurite. Complex silicate of Na, Ca, and Al containing S. U. mass. Gives off H_2S with HCl. Yellow flame. Helvite, similar to Lazurite. Haüynite. Composition similar to lazurite. Contains S as SO_4; does not give H_2S but HCl sol. gives ppt. with $BaCl_2$. Noselite, similar to Haüynite.
	U. in compact acicular, radiate aggregates.	**Pectolite,** $HNaCa_2(SiO_3)_3$. $H = 5$, two perf. clvs.
	Possesses two good cleavages at **nearly right** angles to each other.	**Anorthite,** $CaAl_2Si_2O_8$. Tri. $H = 5$.
	Contain Al, and Ca (tests 4, p. 58). U. prism. in habit, often in more or less compact clusters with radiating arrangement, except Gehlenite, which U. forms short, square crystals.	**Scolecite,** $CaAl(Al.2OH)(SiO_3)_3.2H_2O$. Fuses to a voluminous frothy slag. **Mesolite,** **Thomsonite,** **Laumontite,** } Complex silicates of Na, Ca, and Al. H_2O in C.T. Gehlenite, Silicate of Ca,Mg,Fe and Al. No H_2O in C.T. Fuses with diff. to a gray slag.

Continued on next page.

II—D. *Section b.*—Continued.

	White or colorless. T. crystals.	Apophylite, see beyond. Gives a poor jelly.
	Greasy luster.	Nephelite, see *Section a.*
Decomposed by dilute HCl or HNO_3 with the *separations* of powdery (not gelatinous) **silica** (2, p. 58.)	Fuse with swelling, or intumescence, or both. Prehnite and Wernerite are harder than glass; the others are softer. All but Wernerite yield H_2O in C.T.	WERNERITE, complex silicate of Na, Ca and Al. T. U. cryst. Intense yellow flame. H = 5–6. **Prehnite,** $H_2Ca_2Al_2(SiO_4)_3$. U. in form of greenish botryoidal cryst. crusts. H = 6–6.5. Decomposes slowly with HCl. **Chabazite.** R. U. in rhomb. crystals **Stilbite.** M. U. cryst. in sheaf-like bundles. Clv. pinc. perf. Pearly luster parallel clv. face. **Heulandite.** M. U. cryst. in lozenge-shaped crystals. Clv. pinc. perf. Pearly luster parallel to clv. face. } Hydrous silicates of Na, Ca, and Al. Yield H_2O in C.T. H = 4–4.5.
	Other rare species, some containing Ba and Sr, (zeolites) fall here. See Brush–Penfield, p. 282.	**Apophyllite,** $H_7KCa_4(SiO_3)_8 .4\frac{1}{2} H_2O$. T. U. cryst. Clv. basal perf. Pearly luster parallel base. H = 4.5–5. Test for K. *b*, p. 54.
	Fuses without intumescence.	WOLLASTONITE, $CaSiO_3$. O. Clv. pinc. perf. U. Columnar aggregates. Color. U. white or gray. May give a poor jelly. H = 5.

Continued on next page.

II—D. *Section b.*—Continued.

Soluble in hydrochloric or nitric acids, but do not belong to foregoing sections.			Boracite, $Mg_7Cl_2B_{16}O_{30}$. I. U. cryst.; cubes, tetrahedrons. Cl test 1, p. 35. Greenish flame. H = 7. Colemanite, $Ca_2B_6O_{11}.5H_2O$. M. Clv. 010, perf. Cryst.; also granular, compact. Colorless, white H = 4–4.5. Yellowish-green flame. Decrepitates, exfoliates and fuses imperfectly. Ca test 3, p. 33.
			Amblygonite, $Li(AlF)PO_4$. Tri. U. cryst. mass. Red flame. H = 6. Phosphorus test, 2, p. 52.
			Beryllonite, $NaBePO_4$. O. Colorless. Cryst. Strong yellow flame, tinged with green.
Insoluble in acids.	Hardness less than that of steel.	Fuses easily with intumescence and yields a crimson flame (rarely obscured by sodium).	**Lepidolite,** see *Section a,* p. 131.
		Micaceous structure. Can be split into thin leaves, plates or scales. Fuses rather difficultly.	MUSCOVITE, $H_2KAl_3(SiO_4)_3$. M. Hex. or rhombic plates. Clv. basal perf. Clv. plates colorless and elastic. Found U. with feldspar and quartz. H = 2. Margarite, $H_2CaAl_4Si_2O_{12}$. M. Color U. pink. Clv. basal perf. Leaves brittle. See also Paragonite, soda-mica, p. 145.
		Phosphate test, 2, p. 52. Be test, p. 28.	Herderite, $Ca[Be(F,OH)]PO_4$. M. U. cryst. Colorless. H = 5.
		Finely fibrous.	**Asbestos,** see Tremolite, *Section a,* p. 131.

Continued on next page.

II—D. *Section b.*—Continued.

Insoluble in acids.	Hardness greater than steel.	Colors the flame crimson (Lithia).	**Spodumene.** See *Section a* above. Petalite $(Li,Na)Al(Si_2O_5)_2$. M. U. mass. Clv. basal perf. Fuses quietly.
		Fuses with intumescence.	ZOISITE, $Ca_2(Al.OH)Al_2(SiO_4)_3$. M. U. cryst. prismatic or columnar. U. striated. Clv. pinc. perf. Color white, gray and various light shades. H = 6.
			TOURMALINE, a boro-silicate of Al. and other elements. R. U. prism. and striated vertically; hex. or triangular section. Color green, pink, white. H = 7–7.5. Boron test, 1, p. 31.
		Possess two perfect cleavages at right angles (parallel to the base and the clino, or bracypinacoid)	ORTHOCLASE, $KAlSi_3O_8$. M. (Microcline, Tric.) Often in typical monoclinic crystals. Clv. surfaces unstriated. White, pink, green. H = 6. Sp. G. = 2.57, F = 5. Potash test, *b*, p. 53. ALBITE, $NaAlSi_3O_8$. Tric. Habit is commonly tabular. U. white. Gives little or no K test. H = 6. Sp. G. = 2.62. F = 4–4.5.
			OLIGOCLASE, $3NaAlSi_3O_8.CaAl_2Si_2O_8$. Tric. The basal cleavage surface U. shows fine parallel striæ. U. white. H = 6. Sp. G. = 2.66. F = 4–4.5. Reacts for lime. (4, p. 58.)

Continued on next page.

II—D. *Section b.*—Continued.

Insoluble in acids.	Hardness greater than steel.	Two cleavages at angles of 55 and 125°.	TREMOLITE, $CaMg_3Si_3O_{12}$. M. U. prism. in habit. Color U. white or gray. H=5–6. Ca and Mg test 4, p. 58.
		Crystals are prismatic and have a nearly square cross-section.	PYROXENE (var. Diopside), $CaMgSi_2O_6$. M. Prism. clv. poor. Often shows a basal parting. Color white, pale green. H=5–6. Ca and Mg tests, 4, p. 58.
		U. in simple Hex. prisms of yellowish or greenish color. Diff. fusible.	**Beryl,** $Be_3Al_2(SiO_3)_6$. H. H=7–7.5. U. occurs with quartz and feldspar. Be test, p. 28.
		U. in dodecahedral or trapezohedral crystals.	**Grossularite** (Garnet in part), $Ca_3Al_2(SiO_4)_3$. I. Often granular. Color white, pink, pale yellow or green. Gelatinizes after fusion. H=7.
		Strong yellow flame color.	**Jadeite,** $NaAlSi_2O_6$. U. massive. White, pale green. H=6.5–7.

Division II. SUBDIVISION D. *Section c.* The mineral **fsues** in the forceps to a **colored** or **black glass, enamel** or **slag.**

Impurities or variations in composition may cause some minerals listed in *Sections a* or *b* to fall here. The minerals should therefore be compared with those in corresponding sections of *a* and *b* if any uncertainty exists.

Show special reactions.	Yield a green flame coloration. Strongly colored, red or green.	See Copper Minerals, beyond.

Continued on next page.

II—D. *Section c.*—Continued.

Show special reactions, colors or structures.	Yields a red flame coloration.	See Lithium Minerals, beyond, p. 142.
	Fibrous, silky structure.	Chrysotile, Asbestos, see beyond.
	Dodecahedrous, trapezohedrous.	Garnets, see beyond, p. 142.
	Bright yellow color.	Carnotite, see beyond, p. 142.
	Possess a micaceous structure. When fine grained they consist of an aggregate of small separable scales or plates. Larger crystals can be split easily into thin plates, owing to the highly perfect basal cleavage. The crystals are all monoclinic, but are pseudo-hexagonal or orthorhombic in aspect and U. of tabular habit. H = 2.5–3. All, except vermiculites, are only slightly affected by nitric or hydrochloric acid.	MUSCOVITE, $H_2KAl_3(SiO_4)_3$. See *Section b*, above.
		BIOTITE, $(H,K)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$. M. Often in tabular crysts. Thin leaves, U. brown or greenish-brown, flexible and elastic. Gives little water when heated intensely in C.T.
		PHLOGOPITE. Like biotite, but contains more Mg, also Fluorine. (3, p. 40, may give acid H_2O in C.T. Thin leaves, U. brown or reddish-brown, flexible and elastic.
		Roscoelite, a vanadium mica. Clove to dark greenish-brown. (V. test, 1, p. 72.)
		CHLORITE GROUP. M. Often in tabular crysts. Hydrous silicates of Mg, Fe, and Al. (Vars. clinochlore, ripidolite, penninite, etc.) Color dark green. Thin leaves, are flexible but not elastic. Abundant H_2O in C.T.

Continued on next page.

II—D. *Section c.*—Continued.

Show special structures.	Foliated, micaceous (see preceding page).	TALC, $H_2Mg_3(SiO_3)_4$. M. U. Foliated. White, gray, greenish. Very soft, soapy. (H = 1). Diff. fusible. Vermiculites, complex hydrous silicates, of Mg and Al. Exfoliate prodigiously B.B. Decomposed by acids.
		Chlorotoid, see II—E. *Section g*, beyond.
Show special reactions. Fuses with intumescence, swelling or cracking apart.	Soluble in dilute HNO_3 or HCl and yield **gelatinous** silica upon evaporation. (1, p. 57.)	**Allanite,** cerium bearing Epidote (see below). M. Rare earths, p. 55. Color brown to pitch-black H = 5.5–6. Gadolinite, $FeBe_2Y_2Si_2O_{10}$. Greenish to brownish-black. Swells and cracks B.B. Be test, p. 28. Y. test, p. 55.
	Decomposed by HCl, yielding non-gelatinous silica (2, p. 58).	**Prehnite,** see *Section b.*
	Insoluble or nearly so in HCl or HNO_3.	EPIDOTE, $Ca_2(Al.OH)(Al,Fe)_2(SiO_4)_3$. M. U. in prismatic or columnar crystals. Clv. basal perf. (‖ to elongation). Color yellow-green. H = 6–7. Intumesces only at first. Gelatinizes after fusion.
		VESUVIANITE, essentially a Ca.Al silicate. T. U. cryst. prism. Often radiate. Color U. brown or green. H = 6.5.
		Piedmontite, manganese bearing epidote. Color reddish-brown, reddish-black. (Mn, 1, p. 47.)

Continued on next page.

II—D. *Section c.*—Continued.

Show special reactions. Fuses with **intumescence, swelling or cracking apart.**	Insoluble or nearly so in HCl or HNO_3. Axinite gives a pale green flame color.	TITANITE (Sphene), $CaTiSiO_5$, M. U. in acute crystals. Color U. brown or yellow. Slightly decomposed by acids. Ti, 1, p. 69.
		Axinite. A boro-silicate of Al and Ca (with Fe and Mn). Tric. Crystals broad and acute. $H = 6.7$ Boron, 1, p. 31. Gelatinizes after fusion.
		Some AMPHIBOLES. PYROXENES may intumesce. (See below.) Melilite fuses sometimes with intumescence.
		Tourmaline, see p. 127.
Fuse quietly, or with little intumescence. Soluble in, or decomposed by, hot dilute acids, with effervescence, or with formation of a residue.	Soluble in dilute HNO_3 or HCl with **effervescence,** giving a green solution. Chrysocolla (see beyond) frequently effervesces from admixed malachite.	MALACHITE, $CuCO_3.Cu(OH)_2$. Color green, silky luster. Reduces readily to a copper globule. $H = 3.5–4$.
		AZURITE, $2CuCO_3.Cu(OH)_2$. M. U. crystalline. Color blue. Reduces easily to copper globule. $H = 3.5–4$.
	Soluble in dilute HNO_3 or HCl and yield **gelatinous** silica upon evaporation.	**Troostite**, (Willemite) $(Zn,Mn)_2SiO_4$. R. U. brown, yellow, or green. (Zn, 2, p. 75. Mn, 1, p. 47.)
		Tephroite. Mn_2SiO_4. U. brown.
		Melilite. Formula uncertain, Si,Al, Fe,Ca,Mg,Na. Fuses with slight intumescence.

Continued on next page.

II—D. *Section c.*—Continued.

Fuse quietly or with little intumescence. Soluble in, or decomposed by, hot dilute acids with formation of a residue.	Decomposed in boiling dilute HNO_3 or HCl with the separation of non-gelatinous silica. Diff. fusible.	SERPENTINE, $H_4Mg_3Si_2O_9$. U. mass. Color green or yellowish-green. Abundant H_2O in C.T. Varieties based on structure—**Chrysotile (Asbestos)**, fibrous; Picrolite, splintery; Antigorite, foliated.
	Decomposed by HCl with separation of a **yellow residue.**	**Hübnerite,** $MnWO_4$. Clv. pinc. perf. Color U. brown. W. test, p. 70. Sp. G.=7+. H=5–5.5.
Soluble in dilute acids, but without effervescence, or the separation of silica, or other residue.	Color red.	CUPRITE, Cu_2O. I. Crystals common; also fibrous or granular mass. Reduces easily to copper globule.
	Color green. React for copper.	**Atacamite,** $Cu_2Cl(OH)_3$. O. U. cryst. prismatic. Color emerald-green. Azure-blue flame. Cl. test.
		Brochantite, $CuSO_4.3Cu(OH)_2$. O. U. cryst. Emerald-green. Sulphate test.
		Torbernite, $Cu(UO_2)_2(PO_4)_2.8H_2O$. T. U. Tabular crystals. Clv. basal perf. Color emerald-green. Libethenite, $Cu(Cu.OH)PO_4$. O. Dark olive-green.
	Color yellow.	*Autunite,* $Ca(UO_2)_2(PO_4)_2.8H_2O$. O. U. tabular. Uran. test, 1, p. 71.

Continued on next page.

II—D. *Section c.*—Continued.

Soluble in hot dilute acids.—*Continued.*	Color yellow.	**Carnotite.** A potassium urano-vanadate. Soft, loosely coherent powder. Often in sandstone. U. test, 2, p. 71, V, 2, p. 72.
	Colors the flame red.	Lithiophilite, $Li(Mn,Fe)PO_4$. O. Clv. basal perf. Color salmon or clove-brown. Mn test, 1, p. 47.
Insoluble or nearly so in dilute HNO_3 or HCl. May fuse with a little intumescence.	Very soft (H=1).	TALC, see beyond, p. 151.
	U. crystalline; dodecahedrons or trapezohedrons, also granular. Color pink, reddish-brown, red, dark red. H=7.–7.5. Ca, Mg, Mn, Fe are isomorphous; also Al, Fe and Mn in the garnet molecule. Gelatinize after fusion B.B.	GARNETS, including the following varieties: Grossularite, essentially $Ca_3Al_2(SiO_4)_3$. Pyrope, essentially $Mg_3Al_2(SiO_4)_3$. Spessartite, $(Mn,Fe)_3Al_2(SiO_4)_3$. Almandite, $Fe_3Al_2(SiO_4)_3$ (common garnet).
	Reacts for Mn in borax bead. (2, p. 48.)	**Rhodonite,** $MnSiO_3$. Tri. Color U. red or pink, also brown. Clv. prism. perf. at nearly 90°. The variety Fowlerite contains zinc.
	Amphiboles, Monoclinic crystallization and prismatic in habit. Characterized by a fine prismatic cleavage at angles of 55° and 125°. H=5–6. Tests for bases, 4, p. 58.	**Actinolite,** $Ca(Mg,Fe)_3Si_4O_{12}$. Prismatic habit. Color green. Sp. G. 3. HORNBLENDE. Like the above, but contains Al. Color green to black. Sp. G. 3.2–3.3.

Continued on next page.

II—D. *Section c.*—Continued.

Insoluble or nearly so in dilute HNO_3 or HCl. May fuse with a little intumescence.	**Pyroxenes.** Crystals are Moncl. in habit, with nearly square cross-section. Often show a basal parting. H = 5–6. Tests for bases, see 4, p. 58.	DIOPSIDE (Malacolite), $CaMgSi_2O_6$. Fe isom. w. Mg, and then grades towards Hedenbergite. Colorless, white, pale green. Sp. G. 3.29. HEDENBERGITE, $CaFeSi_2O_6$. Color black. Sp. G. 3.5. AUGITE. Like the above but contains Al. Sp. G. 3.33–3.45. Greenish-black to black color. Common pyroxene of lavas and igneous rocks.
	Difficultly fusible. Color blue or green.	**Iolite.** See p. 152. **Tourmaline.** See p. 153.

Division II. Subdivision E. The mineral is **infusible** B.B., non-volatile, etc.

Section a. The minerals are *white* or *become so on ignition* B.B. The fine powder, *moistened* with *cobalt nitrate solution* and *intensely ignited* B.B., *becomes blue* (alumina or zinc silicate).

Give **gelatinous** silica upon evaporation with acids. (1, p. 57.)	CALAMINE, $(ZnOH)_2SiO_3$. O. U. cryst. in radiating groups. Colorless white, blue. H = 4.5–5. (Zn. test, 2, p. 75.) Allophane, $Al_2SiO_5.5H_2O$. Amorphous, wax-like. H = 3. Sp. G. 1.88. Crumbles B.B.
Slowly soluble in acids.	**Wavellite,** BAUXITE, } See below under next head.

Continued on next page.

II—E. *Section a.*—Continued.

Insoluble, or very slowly soluble in hot dilute HCl or HNO_3. Hardness less than that of steel.	Very soft, H = 1–2.5 H_2O in C.T.	KAOLINITE, $H_4Al_2Si_2O_9$. U. amorphous, compact or earthy. White when pure, commonly stained yellow or red, often impure. For Halloysite, see Dana. **Pyrophyllite,** $H_2Al_2(SiO_3)_4$. Foliated, compact. Clv. basal perf. U. white or buff. Agalmatolite. Pagodite. } Mass. in structure. Pinite. They U. react for potash and are massive, impure substances related in part to muscovite and in part to pyrophyllite. See Dana.
	Aggregates of radiating prisms or fibers. White to green in color.	**Wavellite** $(Al.OH)_3(PO_4)_2.5H_2O$. Slowly decomposed in acids. P test, 2 or 3, pp. 52–3.
	Colorless, but U. apple to emerald-green.	Variscite, $AlPO_4.2H_2O$. U. massive. P test, 2 or 3, pp. 52–3.
	Azure-blue, pyramidal crystals.	Lazulite, $(Mg,Fe)(Al.OH)_2(PO_4)_2$. M. H = 5–5.5 P test, 2 or 3, pp. 52–3.
	Color blue to greenish-blue. Fibrous to columnar aggregates.	Dumortierite. An aluminium silicate. May contain boron. H = 7.
	U. in bladed crystals. Clv. pinc. perf. ∥ to elongation.	CYANITE, Al_2SiO_5. Tric. Scratches easily ∥ to elongation. Basal parting. Striated ∥ to length.
	White. Fibrous.	**Fibrolite,** Al_2SiO_5. O. Clv. pinc. perf.
	Incrustations, Stalactitic.	**Gibbsite,** $Al(OH)_3$.

Continued on next page.

II—E. *Section a.*—Continued.

Insoluble, or very slowly soluble in hot dilute HCl or HNO_3. Hardness less than that of steel	Concretionary structure, earthy, also compact.	BAUXITE, $Al_2O_3.XH_2O$. White, brown, reddish. Often impure.
	Massive and as minute crystals.	**Alunite** $(K,Na)(Al.2OH)_3(SO_4)_2$. Hex. R. Color white.
	Massive, or consisting of fine scales. Fuses with diff. Sodium flame color.	Pargonite, $Na_2O.3Al_2O_3.6SiO_2.2H_2O$. Soda mica.
Insoluble in hot dilute HNO_3 or HCl. Hardness greater than steel or glass. The minerals are arranged in order of decreasing hardness.	Crystals hex. in habit. Extremely hard. Various colors, white, gray, brown, pink, red, blue.	CORUNDUM, Al_2O_3.—Hex. rhomb. Commonly shows a nearly cubical parting or cleavage. Cleav. surfaces striated $\parallel$ to edges. H=9. Sp. G. 3.9 to 4.1.
	Green crystals, various shades.	Chrysoberyl, $BeAl_2O_4$. O. H=8.5. Sp. G.=3.6–3.8. Be test, p. 28.
	U. as octahedral crystals. U. dark green or gray, sometimes pink or red.	**Spinel,** $(Mg,Fe)Al_2O_4$. I. Gahnite, or zinc spinel, reacts for zinc with Na_2CO_3 and carbon B.B. H=8+.
	U. as colorless or brown, orthorhombic crystals.	**Topaz,** $(AlF)_2SiO_4$. O. Clv. basal perf. H=8. Sp. G.=3.55. Fluorine test, 2, p. 40.
	U. as elongated prisms. (Fibrous form, see fibrolite above.)	**Sillimanite,** Al_2SiO_5. O. Clv. pinc. perf. white, brown. H=7. Sp. G. 3.2.
	U. as stout rect. prisms. in mica schist.	ANDALUSITE (Chiastolite), Al_2SiO_5. O. H=7.5. Commonly contains inclusions.

Continued on next page.

II—E. *Section a.*—Continued.

Insoluble in hot dilute HNO_3 or HCl. Hardness greater than steel or glass. The minerals are arranged in order of decreasing hardness.	Pink to nearly colorless prisms or columnar aggregates often radiating and U. striated longitudinally.	**Tourmaline,** a borosilicate of Al and other elements. R. The crystal cross-section, is often triangular. Reacts for Boron, 1, p. 31. H=7+.
	Trapezohedral crystals. Decomposed with the separation of non-gelatinous silica.	LEUCITE, $KAlSi_2O_6$. I. Occurs U. as embedded gray or white crystals in basalt. H=5.5–6. Potash test, b, p. 53.
	Long, bladed crystals. U. blue or green in color. Clv. pinc. perf.	CYANITE, Al_2SiO_5. O. H. greater than steel in a direction at right angles to elongation of crystal.
	U. in flattened crystals. Gives water in C.T.	Diaspore, AlO(OH). O. Clv. pinc. perf. Sol. in salt of phos. bead. H=6.
	Blue, pyramidal crystals.	Lazulite. See above. H=5–5.5.

II—E. *Sections b* and *c*.

Section b. B.B. in R.F. become black and when cold are **attracted by the** magnet.	**Red streak.**	HEMATITE, **Turgite,** See p. 115.
	Yellow to **ochre-brown streak.**	LIMONITE, **Goethite,** See p. 116.
	Carbonates. Effervesce in hot HCl with evolution of CO_2. When crystalline all but zaratite possess a perf. Rhomb. cleav.	SIDERITE, (Spathic iron), $FeCO_3$. R. Color brown. Weathered surfaces, often rusty. **Breunnerite,** $(Mg,Fe)CO_3$. R. Color brown, gray, rarely white. **Ankerite,** $Ca(Mg,Fe)(CO_3.)_2$. R. Color brown, gray, rarely white. RHODOCHROSITE. See below under *c*. May contain enough iron to become magnetic.

Continued on next page.

II—E. *Section b.*—Continued; *Section c.*

Section b. B.B. in R.F. —*Continued.*	Carbonates.—*Continued.*	Zaratite. Hydrous carbonate of Ni. Color emerald-green. U. as incrustations. (Ni test, 1, p. 50.)
Section c. Soluble in hot dilute HCl or HNO_3, with effervescence (mostly carbonates test, B, 1, p. 34).	**Sulphide.** Gives off hydrogen sulphide (odor) with hot HCl.	SPHALERITE, ZnS. I. Cleav. in six directions perf. Color yellow to brown, also reddish, highly lustrous. Zn test, 2, p. 72. H=3.5–4.
	Rhombohedral Carbonates. **Clv. easy and perf.** || to three equally inclined directions (Rhomb). H=3–4.5.	CALCITE, $CaCO_3$. R. Commonly in fine crystals of various habits; also granular, compact. Colorless, white and various light shades. Effervesces freely, even in very dilute (1–20)HCl or HNO_3. H=3. Sp. G.=2.72. Chalk, an earthy variety. DOLOMITE, $CaMg(CO_3)_2$. R. Crystals and cleav. surfaces often curved; also granular, compact. Colors varied, U. white, pinkish, gray. Little or no effervescence in cold dilute acids. H=3.5–4. Sp. G. 2.85. Mg test, 1, p. 47. MAGNESITE, $MgCO_3$. U. cryst. also massive. U. white, gray or light brown. H=3.5–4.5, Sp. G. =3. Mg 1, p. 47. RHODOCHROSITE, $MnCO_3$. R. Color pink to red, also brown. H=3.5–4.5. Sp. G.=3.5. Mn test, 1, p. 47.

Continued on next page.

II—E. *Section c.*—Continued; *Section d.*

Section c.—Continued.—Soluble in hot dilute HNO_3 or HCl with effervescence (B, 1, p. 34), carbonates.	Rhombohedral carbonates.—*Continued.*	SMITHSONITE, $ZnCO_3$. Often contaminated with iron, copper, etc. R. (See Div. II, B. *g*). Botryoidal, encrusted. Colors varied in light shades. H=5. Sp. G. 4.4. (Zn test, 1, p. 74.)
	Soft. U. white and massive.	Hydrozincite, $3ZnO.CO_2.2H_2O$, Massive, often encrusted, earthy, fibrous. H_2O in C.T. Zn test, 1 p. 74.
	Color pale green or blue. U. acicular, encrusted.	**Aurichalcite**, $2(Zn,Cu)CO_3.3(Zn,Cu)(OH)_2$. H=2 (Zn test, 1, p. 74. Cu test, 3, p. 39.)
	Crystals, and in columnar or acicular aggregates. Color U. white. Cleav. poor.	ARAGONITE, $CaCO_3$. O. Effervesces in very dilute acids like calcite. H=3.5–4. Sp. G.=2.95. **Strontianite**, $SrCO_3$. O. Yields a crimson flame color. H=3.5–4. Sp. G.=3.7. Sr test, 3, p. 64.
	Acicular, tufted, also earthy.	Hydromagnesite, $3MgCO_3.Mg(OH)_2.3H_2O$. H=3.5. Mg test, 1 or 2, p. 47.

For other rare species, see B. & P., p. 289.

Section d. Completely soluble in boiling dilute HCl, but do not yield silica upon evaporation nor effervesce.	U. in simple hexagonal prismatic crystals. U. green or brown.	APATITE, $Ca_4(CaF)(PO_4)_3$. H. H=5. Phosphate test, 2, p. 52. May give a slight effervescence.
	Color U. orange-red or dark red. Streak orange or yellow.	Zincite, (Zn,Mn)O. H=4+. Cleav. basal perf. Zn test, 1 or 2, pp. 74–5. Mn test, 1, p. 47.

Continued on next page.

II—E. *Section d.*—Continued; *Section e.*

Section d. Completely soluble in boiling dilute HCl, but do not yield silica upon evaporation nor effervesce	Cubes, octahedrons, also granular.	Periclase, MgO. I. Clv. cubic, perf. $H=6$. Color U. white.
	U. foliated. Color white. Soft.	**Brucite,** $Mg(OH)_2$. H. Cleavage basal perf. $H=2$. H_2O in C.T.

For a considerable number of rare minerals which fall here, Sulphates and Phosphates chiefly, see B. & P., pp. 290 to 293.

Section e. Decomposed by boiling HCl with the separation of a residue (mostly silicates).	Decomposes with the formation of a bright yellow residue (tungstic oxide).	**Scheelite,** $CaWO_4$. T. White, yellow, brown, green. $H=4–5.5$. Sp. G. 6.05. W test 1, p. 70.
	Decomposed with separation of non-gelatinous silica. 2, p. 58.	SERPENTINE, $H_4Mg_3Si_2O_9$. See Div. II. D. *Section c.*
		LEUCITE, $KAlSi_2O_6$. I. White or colorless. Trapezohedral crystals. $H=5.5–6$. K test 1, *b*, p. 53.
		CHRYSOCOLLA, $CuSiO_3 2H_2O$. U. amorphous, massive. Color bluish-green.
		Garnierite, $H_4(Ni,Mg)_2Si_3O_{12}.4H_2O$, but variable. Amorph. botryoidal. Green color. Ni test, 2 or 3, p. 50–1.
		Deweylite (Gymnite), Hydrous Mg silicate. Amorphous.

Continued on next page.

II—E. *Section e.*—Continued; *Section f.*

Section e. Decomposed by boiling acids, etc.—*Continued.*	Decomposed with separation of non-gelatinous silica. 2 p. 58.	Sepiolite, $H_4Mg_2(Si_3O_{10})$. (Meerschaum.) Compact, earthy. White color. Sp. G. = 2. H = 2–2.5.
		Pollucite, $H_2Cs_4Al_4(SiO_3)_9$. U. massive cryst.; resembles quartz.

See also B. & P., p. 295, for other species.

Section f. **Soluble in boiling HCl and yield gelantinous silica** upon evaporation.	Color pale green or yellowish-green. U. granular.	CHRYSOLITE, (Olivine) $(Mg,Fe)_2SiO_4$. O. Found in basalts and certain basic rocks. H = 6.5–7. Must be finely powdered to yield Silica gel. Fe and Mg tests, 4, p. 58.
		Willemite, $(Zn,Mn)SiO_4$. Hex. R. React for zinc, 2, p. 75.
	Color emerald-green. U. cryst.	Dioptase, H_2CuSiO_4. Clv. Rhomb. perf.
	U. in brown or reddish-brown cryst. grains.	**Chondrodite,** $Mg_3[Mg(F,OH)](SiO_4)_2$. Often found in limestone. Mg test, 1, p. 47. F test, 1, p. 39.
	B.B. swells, cracks, and often glows. Color black or nearly so.	Gadolinite, $FeBe_2Y_2Si_2O_{10}$. H = 6.5–7. Sp. G. 4.2–4.5. Yttrium test, p. 55.
	Sp. G. 4.2–4.9. React for rare earth metals (p. 55).	Thorite, $ThSiO_4$. T. Th test, p. 55.
		Cerite. Hydrous silicate of cerium and iron. Sp. G. 4.9. U. massive.

See also B. & P., p. 294 for other species.

II—E. *Section g.* **Insoluble** or practically so in boiling HCl or HNO_3.

Hardness less than steel.	**Very soft.** Soapy feel.	TALC, $H_2Mg_3(SiO_3)_4$. M. U. foliated, fibrous, or massive. White, gray, green. H = 1.
	Micaceous structure (Aggregation of easily separable scales or plates. Large crystals yield sheets.)	MICAS. See p. 138. Sheets are flexible and elastic. H = 2. Colorless, brown, to almost black.
		The CHLORITES. See page p. 138. Sheets are flexible, but not elastic. H = 2. Color green to almost black.
		Brittle micas (Chloritoid, etc.). Hydrous, silicates of Ca, Mg and Al. Colors green, brown, yellowish, reddish, gray. Margarite is pink. The leaves or flakes are brittle.
	Pale to deep green. Amorphous, botryoidal.	**Garnierite.** See p. 149.
	Yellowish to reddish-brown crystals. Phosphorus, 2, p. 52. Rare earths, p. 55.	**Monazite,** $(Ce,La,Di)PO_4$. M. Often found as rounded grains in sand. H = 5–5.5. Xenotime, YPO_4.T. U. cryst. Clv. prism. perf.

For other species, see B. & P., pp. 296 to 298.

Hardness equal or greater than steel.	Color black, streak brown.	CHROMITE, $FeCr_2O_4$ with $MgAl_2O_4$. I. Octahedral crysts. Commonly granular. H = 6–7. Cr test, 1, p. 36. Sp. G. = 4.2–4.5.

Continued on next page.

II—E. *Section g.*—Continued.

Hardness equal or greater than steel.	Color black, brown, red, reddish-brown. React for titanium (1, p. 69). Several other rare compounds of Ti and other rare elements fall here. Brush - Penfield, pp. 297–8.	RUTILE. T. Crystals prism., striated, often twinned. H. =6–6.5. Sp. G.=4.18–4.25. Octahedrite. T. Crystals U. acute pyramids. H=5.5–6. Sp. G.=3.8–3.95. Brookite, O. U. cryst. H=6. Sp. G.=4.0.	TiO_2
		Perowskite, $CaTiO_3$. I. Commonly in cubes or octahedrons. H=5.5. Sp. G.=4.03.	
	High Sp. G.=6.8–7.1. Color U. brown, reddish-brown to black.	CASSITERITE (Tinstone), SnO_2. T. Crystals lustrous, often twinned. Occurs often in botryoidal forms and as grains in sand (stream tin). H=6–7. Sn test, 1, p. 69.	
	Color emerald-green.	Uvarovite (chrome-garnet), Crystals, duodecahedral. H=7. Sp. G.=3.4. Chromium, 1, p. 36.	
	Color green or **turquois-blue.**	**Turquois,** $H(Al.2OH)_2PO_4$. Contains copper also. Massive. H=6. Phosphorus test, 2, p. 52.	
	Color light to dark **blue.**	Iolite (Cordierite). $H_2(Mg,Fe)_4Al_8Si_{10}O_{37}$. H=7–7.5. Sp. G.=2.61.	
	Possess **two perf. cleav**ages at right angles to each other. Diff. fusible.	THE FELDSPARS. Orthoclase and Microcline. See p. 136. U. White, pink, green. H=6.	
	Clear or frosted crystals (Oct.). Grains of extreme hardness.	Diamond. I. Clv. Oct., perf. Colorless and light shades. Rarely black and amorphous. H=10. Sp. G.=3.52.	

Continued on next page.

II—E. *Section g.*—Continued.

Hardness greater than steel	**Tetrag. crystals,** U. of simple forms.	ZIRCON, $ZrSiO_4$. T. H = 7.5. Sp. G. = 4.68. Color U. brown. Often in sands. Zirconia test, 1, p. 75.
	Yellow, brown to black cryst. grains.	Baddeleyite (Brazilite) ZrO_2. Zirkelite, $(Ca,Fe)O.2(Zr,Th,Ti)O_2$.
	Clear, glassy, also white and in various colors. Commonly cryst. in Hex. well terminated prisms. Prisms horizontally striated.	QUARTZ, SiO_2. Hex. Rhomb. Conchoidal fracture. Also granular compact. Abundant in sand. The powder mixed with equal volumes of Na_2CO_3 yields a clear glass B.B. H = 7. Sp. G. = 2.65.
	U. in simple Hex. prisms. U. green or yellow in color.	**Beryl,** $Be_3Al_2(SiO_3)_6$. H = 7–7.5. Sp. G. = 2.7–2.75. Beryllium test, p. 28. U. assoc. with quartz and feldspar.
	Prismatic crystals, frequently in columnar aggregates. Color U. pink, or green to greenish-black.	TOURMALINE, a boro-silicate of Al and other elements. Rhomb. Crysts. U. striated and of hex. or triangular section. H = 7–7.5. Sp. G. = 3–3.1. Boron test, 1, p. 31.
	In simple ortho. crystals; often twinned. Color reddish-brown, brown to black.	STAUROLITE, complex silicate of Fe and Al. H = 7–7.5 Sp. G. = 3.75–3.78.
	Yellow, brown, green to black. Become black B.B. Sometimes slightly magnetic (hypersthene).	**Enstatite,** $MgSiO_3$. O. **Hypersthene,** $(Mg,Fe)SiO_3$. O. Constituents of basic igneous rocks. H = 5–6. Sp. G. = 3.1 to 3.3.

Continued on next page.

II—E. *Section g.*—Continued.

Hardness greater than steel.	Massive, botryoidal, stalactic, encrusted, wax-like. Various colors.	CHALCEDONY, SiO_2. Reactions as for quartz. H = 7. Sp. G. = 2.6–2.64. Varieties. Agate, Flint, Chert, Jasper, etc. See Dana.
	Various colors, also colorless. Sometimes shows a play of colors. Amorphous, glassy.	OPAL, SiO_2+water. (Hyalite, colorless opal), Wood opal, Fire opal.) H = 5.5–6.5. Sp. G. = 2.1–2.2. Yields a little H_2O on intense ignition B.B. See Dana.

For many other rare minerals, see B. & P., pp. 298, *et seq.*

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